ASTRONOMY,

EXPLAINED UPON

SIR ISAAC NEWTON'S PRINCIPLES.

BY

JAMES FERGUSON, F. R. S.

WITH

NOTES, AND SUPPLEMENTARY CHAPTERS.

BY

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TO

THE RIGHT HONOURABLE

THE

EARL OF LAUDERDALE,

THIS ENLARGED EDITION

OF

FERGUSON'S ASTRONOMY

IS INSCRIBED

BY

HIS LORDSHIP'S MOST OBEDIENT, AND

OBLIGED SERVANT,

THE

EDITOR

PREFACE

OF

THE EDITOR.

In presenting to the Public a new and enlarged edition of Ferguson's Astronomy, the Editor has been particularly solicitous to collect all the discoveries in the science which have been made during the last thirty years, and to present them in a simple and unassuming form suited to the popular nature of the original work. These discoveries, which are contained in Twelve supplementary Chapters, relate chiefly to the physical constitution of the Old and New Planets of the Solar System, and to the various and wonderful phenomena which are displayed in the region of the Fixed Stars.

In accomplishing this task, the Editor can claim no other merit but that of having brought together a

number of curious facts, which had not hitherto been collected, and many of which have never appeared in any English work. In this new edition, various additions and improvements have been made, and an additional Chapter has been added on Practical Astronomy.

Edinburgh, February 1, 1821.

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FIRST VOLUME.

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ASTRONOMY

EXPLAINED UPON

SIR ISAAC NEWTON'S PRINCIPLES.

CHAP I.

OF ASTRONOMY IN GENERAL.

1. Of all the sciences cultivated by mankind, astronomy is acknowledged to be, and undoubtedly is, the most sublime, the most interesting, and the most useful; for, by knowledge derived from this science, not only the bulk of the earth is discovered, the situation and extent of the countries and kingdoms upon it ascertained, trade and commerce carried on to the remotest parts of the world, and the various products of several countries distributed for the health, comfort, and conveniency of its inhabitants; but our very faculties are enlarged with the grandeur of the ideas it conveys, our minds exalted above the low contracted prejudices of the vulgar, and our understandings clearly convinced, and affected with the conviction, of the existence, wisdom, power, goodness, immutability, and superintendency of the Supreme Being! So that, without an hyperbole,

The general use of Astronomy.

"An undevout astronomer is mad."[1]

2. From this branch of knowledge we also learn by what means or laws the Almighty carries on, and continues, the won-

[1] Dr. Young's Night Thoughts.

derful harmony, order, and connexion observable throughout the planetary system; and are led by very powerful arguments to form this pleasing deduction, that minds capable of such deep researches, not only derive their origin from that Adorable Being, but are also incited to aspire after a more perfect knowledge of his nature, and a stricter conformity to his will.

The Earth but a point as seen from the Sun.

3. By astronomy we discover that the Earth is at so great a distance from the Sun, that if seen from thence it would appear no bigger than a point; although its circumference is known to be 25,020 miles. yet that distance is so small, compared with the Earth's distance from the fixed stars, that if the orbit in which the Earth moves round the Sun were solid, and seen from the nearest star, it would likewise appear no bigger than a point, although it is at least 162 millions of miles in diameter: for the Earth in going round the Sun is 162 millions of miles nearer to some of the stars at one time of the year than at another; and yet their apparent magnitudes, situations, and distances, from one another still remain the same; and a telescope which magnifies above 200 times does not sensibly magnify them which proves them to be at least 100,000 times farther from us than we are from the Sun.

The stars are suns.

4. It is not to be imagined that all the stars are placed in one concave surface, so as to be equally distant from us; but that they are placed at immense distances from one another through unlimited space so that there may be as great a distance between any two neighbouring stars, as between our Sun and those which are nearest to him. Therefore an observer, who is nearest any fixed star, will look upon it alone as a real sun; and consider the rest as so many shining points, placed at equal distances from him in the firmament.

and innumerable.

5. By the help of telescopes we discover thousands of stars which are invisible to the bare eye; and the better our glasses are, still the more become visible: so that we can set no limits either to their number or their distances. The celebrated Huygens carried his thoughts so far, as to believe it not impossible that there may be stars at such inconceivable distances, that their light has not yet reached the earth since its creation; although the velocity of light be a million of times greater than the velocity of a cannon bullet, as shall be demonstrated afterwards, § 197, 216: and, as Mr. Addison

very justly observes, this thought is far from being extravagant, when we consider that the universe is the work of infinite power, prompted by infinite goodness; having an infinite space to exert itself in; so that our imaginations can set no bounds to it.

Why the Sun appears bigger than the stars.

6. The Sun appears very bright and large in comparison of the fixed stars, because we keep constantly near the Sun, in comparison of our immense distance from the stars. For, a spectator placed as near to any star as we are to the Sun, would see that star a body as large and bright as the Sun appears to us: and a spectator, as far distant from the Sun as we are from the stars, would see the Sun as small as we see a star, divested of all its circumvolving planets; and would reckon it one of the stars in numbering them.

The stars are not enlightened by the Sun.

7. The stars being at such immense distances from the Sun, cannot possibly receive from him so strong a light as they seem to have; nor any brightness sufficient to make them visible to us. For the Sun's rays must be so scattered and dissipated before they reach such remote objects, that they can never be transmitted back to our eyes, so as to render these objects visible by reflection. The stars therefore shine with their own native and unborrowed lustre, as the Sun does; and since each particular star, as well as the Sun, is confined to a particular portion of space, it is plain that the stars are of the same nature with the Sun.

They are probably surrounded by planets.

8. It is nowise probable that the Almighty, who always acts with infinite wisdom, and does nothing in vain, should create so many glorious suns, fit for so many important purposes, and place them at such distances from one another, without proper objects near enough to be benefited by their influences. Whoever imagines they were created only to give a faint glimmering light to the inhabitants of this globe, must have a very superficial knowledge of astronomy, and a mean opinion of the Divine wisdom: since, by an infinitely less exertion of creating power, the Deity would have given our earth much more light by one single additional moon.

9. Instead then of one Sun and one world only in the universe, as the unskilful in astronomy imagine, that science discovers to us such an inconceivable number of suns, systems, and worlds, dispersed through boundless space, that if our Sun,

with all the planets, moons, and comets, belonging to it, were annihilated, they would be no more missed, by an eye that could take in the whole creation, than a grain of sand from the sea-shore; the space they possess being comparatively so small, that it would scarce be a sensible blank in the universe, although Saturn, the outermost of our planets, revolves about the Sun in an orbit of 4,884 millions of miles in circumference, and some of our comets make excursions upwards of ten thousand millions of miles beyond Saturn's orbit; and yet, at that amazing distance, they are incomparably nearer to the sun than to any of the stars; as is evident from their keeping clear of the attractive power of all the stars, and returning periodically by virtue of the Sun's attraction.

The stellar planets may be habitable.

10. From what we know of our own system, it may be reasonably concluded that all the rest are with equal wisdom contrived, situated, and provided, with accommodations for rational inhabitants. Let us therefore take a survey of the system to which we belong; the only one accessible to us; and from thence we shall be the better enabled to judge of the nature and end of the other systems of the universe. For although there is almost an infinite variety in the parts of the creation, which we have opportunities of examining, yet there is a general analogy running through and connecting all the parts into one scheme, one design, one whole!

As our solar planets are.

11. And then, to an attentive observer, it will appear highly probable, that the planets of our system, together with their attendants called satellites or moons, are much of the same nature with our Earth, and destined for the like purposes; for they are solid opaque globes, capable of supporting animals and vegetables. Some of them are bigger, some less, and some much about the size of our earth. They all circulate round the Sun, as the Earth does, in a shorter or longer time, according to their respective distances from him; and have, where it would not be inconvenient, regular returns of summer and winter, spring and autumn. They have warmer and colder climates, as the various productions of our earth require: and, in such as afford a possibility of discovering it, we observe a regular motion round their axes like that of our Earth, causing an alternate return of day and night; which is necessary for labour, rest, and vegetation, and that all parts of their surfaces may be exposed to the rays of the Sun.

12. Such of the planets as are farthest from the Sun, and therefore enjoy least of his light, have that deficiency made up by several moons, which constantly accompany and revolve about them, as our moon revolves about the earth. The remotest planet has, over and above, a broad ring encompassing it; which like a lucid zone in the heavens reflects the sun's light very copiously on that planet: so that if the remoter planets have the Sun's light fainter by day than we, they have an addition made to it morning and evening by one or more of their moons, and a greater quantity of light in the night-time.

The farthest from the Sun have most moons to enlighten their nights.

13. On the surface of the Moon, because it is nearer to us than any other of the celestial bodies are, we discover a nearer resemblance of our Earth; for, by the assistance of telescopes, we observe the moon to be full of high mountains, large valleys, and deep cavities. These similarities leave us no room to doubt, but that all the planets and moons in the system are designed as commodious habitations for creatures endowed with capacities of knowing and adoring their beneficent creator.

Our Moon mountainous like the Earth.

14. Since the fixed stars are prodigious spheres of fire, like our Sun, and at inconceivable distances from one another, as well as from us, it is reasonable to conclude they are made for the same purposes that the Sun is; each to bestow light, heat, and vegetation, on a certain number of inhabited planets, kept by gravitation within the sphere of its activity.

15. What an august, what an amazing conception, if human imagination can conceive it, does this give of the works of the Creator! Thousands of thousands of suns, multiplied without end, and ranged all around us, at immense distances from each other, attended by ten thousand times ten thousand worlds, all in rapid motion, yet calm, regular, and harmonious, invariably keeping the paths prescribed them; and these worlds peopled with myriads of intelligent beings, formed for endless progression in perfection and felicity!

Numberless suns and worlds.

16. If so much power, wisdom, goodness, and magnificence is displayed in the material creation, which is the least considerable part of the universe, how great, how wise, how good must HE be, who made and governs the whole!

CHAP. II.

A BRIEF DESCRIPTION OF THE SOLAR SYSTEM.

PLATE I. Fig. 1. The Solar system. 17. THE Sun, with the planets and comets which move round him as their centre, constitute the solar system. Those planets which are near the Sun not only finish their circuits sooner, but likewise move faster in their respective orbits, than those which are more remote from him. Their motions are all performed from west to east, in orbits nearly circular. Their names, distances, bulks, and periodical revolutions, are as follow:

The Sun. 18. The Sun ☉, an immense globe of fire, is placed near the common centre, or rather in the lower focus,[1] of the orbits of all the planets and comets;[2] and turns round his axis in 25 days 6 hours, as is evident by the motion of spots seen on his surface. His diameter is computed to be 763,000 miles; and, by the various attractions of the circumvolving planets, he is agitated by a small motion round the centre of gravity of the system. All the planets, as seen from him, move the same way, and according to the order of signs in the graduated circle ♈ ♉ ♊ ♋, &c. which represents the great ecliptic in the heavens: but, as seen from any one planet, the rest appear sometimes to go backward, sometimes forward, and sometimes to stand still; not in circles nor ellipses, but[3] in looped

1 If a thread be tied loosely round two pins stuck in a table, and moderately stretched by the point of a black-lead pencil carried round by an even motion and light pressure of the hand, an oval or ellipsis will be described; the two points where the pins are fixed being called the foci or focuses thereof. The orbits of all th planets are elliptical, and the Sun is placed in or near to one of the foci of each of them; and that in which he is placed is called the lower focus.

2 Astronomers are not far from the truth, when they reckon the Sun's centre to be in the lower focus of all the planetary orbits. Though, strictly speaking, if we consider the focus of Mercury's orbit to be in the Sun's centre, the focus of Venus's orbit will be in the common centre of gravity of the Sun and Mercury; the focus of the Earth's orbit in the common centre of gravity of the Sun, Mercury, and Venus; the focus of the orbit of Mars in the common centre of gravity of the Sun, Mercury, Venus, and the Earth; and so of the rest. Yet, the focuses of the orbits of all the planets, except Saturn, will not be sensibly removed from the centre of the Sun; nor will the focus of Saturn's orbit recede sensibly from the common centre of gravity of the Sun and Jupiter.

3 As represented in plate III, fig. 1, and described § 138.

curves, which never return into themselves. The comets come from all parts of the heavens, and move in all sorts of directions.

19. Having mentioned the Sun's turning round his axis, and as there will be frequent occasion to speak of the like motion of the Earth and other planets, it is proper here to inform the young tyro in astronomy, that neither the Sun nor planets have material axes to turn upon, and support them, as in the little imperfect machines contrived to represent them; for the axis of a planet is a line conceived to be drawn through its centre, about which it revolves as if on a real axis. The extremities of this line, terminating in opposite points of the planet's surface, are called its poles. That which points towards the northern part of the heavens, is called the north pole: and the other, pointing towards the southern part, is called the south pole. A bowl whirled from one's hand into the open air, turns round such a line within itself, whilst it moves forward; and such are the lines we mean, when we speak of the axes of the heavenly bodies.

The axes of the planets, what.

20. Let us suppose the Earth's orbit to be a thin, even, solid plane, cutting the Sun through the centre, and extended out as far as the starry heavens, where it will mark the great circle called the ecliptic. This circle we suppose to be divided into 12 equal parts, called signs; each sign into 30 equal parts, called degrees; each degree into 60 equal parts, called minutes; and every minute into 60 equal parts, called seconds: so that a second is the 60th part of a minute; a minute the 60th part of a degree; and a degree the 360th part of a circle, or 30th part of a sign. The planes of the orbits of all the other planets likewise cut the Sun in halves; but, extended to the heavens, form circles different from one another, and from the ecliptic; one-half of each being on the north side, and the other on the south side of it. Consequently the orbit of each planet crosses the ecliptic in two opposite points, which are called the planet's nodes. These nodes are all in different parts of the ecliptic; and therefore, if the planetary tracks remained visible in the heavens, they would in some measure resemble the different ruts of waggon-wheels, crossing one another in different parts, but never going far asunder. That node, or intersection of the orbit of any planet with the Earth's orbit, from which the planet ascends northward above the ecliptic, is called the ascend-

Their orbits are not in the same plane with the ecliptic.

Their nodes.

ing node of the planet: and the other, which is directly oppo-
site thereto, is called its descending node. Saturn's ascending node is in the 21° 13′ of Cancer ♋, Jupiter's in 7° 29′ of the same sign, Mars's in 17° 17′ of Taurus ♉, Venus's in 13° 59′ of Gemini ♊, and Mercury's in 14° 43′ of Taurus.[4] Here we consider the Earth's orbit as the standard, and the orbits of all the other planets as oblique to it.

where situated.

The planets' orbits, what. 21. When we speak of the planets' orbits, all that is meant is their paths through the open and unresisting space in which they move, and are kept in, by the attractive power of the Sun, and the projectile force impressed upon them at first; between which power and force there is so exact an adjustment, that they continue in the same tracks without any solid orbits to confine them.

Mercury. Fig. 1. 22. MERCURY, the nearest planet to the Sun, goes round him (as in the circle marked ☿) in 87 days 23 hours of our time nearly; which is the length of his year. But being seldom seen, and no spots appearing on his surface or disc, the time of his rotation on his axis, or the length of his days and nights, is as yet unknown. His distance from the Sun is computed to be 32 millions of miles, and his diameter 2,600. In his course round the Sun, he moves at the rate of 95,000 miles every hour. His light and heat from the Sun are almost seven times as great as ours; and the Sun appears to him almost seven times as large as to us. The great heat on this planet is no argument against its being inhabited; since the Almighty could as easily suit the bodies and constitutions of its inhabitants to the heat of their dwelling, as he has done ours to the temperature of our Earth. And it is very probable that the people there have such an opinion of us as we have of the inhabitants of Jupiter and Saturn; namely that we must be intolerably cold, and have very little light at so great a distance from the Sun.

May be inhabited.

[4] On the 1st of January 1820, the ascending node of the Georgium Sidus, one of the planets lately discovered, was in the 12° 57′ of Gemini, and advances 1[illegible] seconds in a year. Saturn's in 22° 56′ of Cancer, and advances 32 seconds in a year. Jupiter's in 8° 36′ of Cancer, and advances 36 seconds every year. Mars' in 18° 11′ of Taurus, and advances 28 seconds in a year. Venus's in the 15° 4[illegible] of Gemini, and advances 30 seconds in a year. Mercury's in 16° 11′ of Taurus and advances 43 seconds every year. It is a curious circumstance that the node of the planets should all be in the 2d, 3d, and 4th signs of the zodiac, and that two nodes should be in each of these signs.—*Ed.*

Has like phases with the Moon.

23. This planet appears to us with all the various phases of the Moon, when viewed at different times by a good telescope: save only that he never appears quite full, because his enlightened side is never turned directly toward us, but when he is so near the Sun as to be lost to our sight in its beams. And, as his enlightened side is always towards the Sun, it is plain that he shines not by any light of his own; for if he did, he would constantly appear round. That he moves about the Sun in an orbit within the Earth's orbit, is also plain (as will be more largely shewn by and by, § 141, *et seq.*), because he is never seen opposite to the Sun, nor above 56 times the Sun's breadth from his centre.

His orbit and nodes.

24. His orbit is inclined seven degrees to the ecliptic; and that node, § 20, from which he ascends northward above the ecliptic, is in the 16th degree of Taurus; the opposite in the 16th degree of Scorpio. The Earth is in these points on the 6th of November and 4th of May, new style; and when Mercury comes to either of his nodes at his inferior[5] conjunction about these times, he will appear to pass over the disc or face of the Sun, like a dark round spot. But in all other parts of his orbit his conjunctions are invisible, because he either goes above or below the Sun.

When he will be seen as if upon the Sun.

25. Mr. Whiston has given us an account of several periods at which Mercury may be seen on the Sun's disc, viz. in the year 1782, November 12, at $3^h\ 44^m$ in the afternoon; 1786, May 4, at $6^h\ 57^m$ in the forenoon; 1789, December 6, at $3^h\ 55^m$ in the afternoon; and 1799, May 7, at $2^h\ 34^m$ in the afternoon.[6]

Venus.

Plate I, Fig. 1.

26. VENUS, the next planet in order, is computed to be 59 millions of miles from the Sun; and by moving at the rate of 69,000 miles every hour in her orbit (as in the circle marked ♀), she goes round the Sun in 224 days 17 hours of our time, nearly; in which, though it be the full length of her year, she has only $9\frac{1}{4}$ days, according to Bianchini's observations;[7] so that, to

[5] When he is between the Earth and the Sun in the nearer part of his orbit.

[6] The next visible transits of Mercury will be in 1832, May 5, middle of the transit, $12^h\ 27^m$ noon; 1845, May 8, $7^h\ 42^m$ in the afternoon; 1848, November 9, $1^h\ 59^m$ in the afternoon; 1861, November 12, $7^h\ 30^m$ morning; 1868, November 5, $7^h\ 28^m$ in the morning; 1878, May 7, $6^h\ 5^m$ in the afternoon; 1894, November 10, $6^h\ 46^m$ in the evening.—*Ed.*

[7] According to the elder Cassini, Venus revolves upon her axis in the space of

her, every day and night together is as long as 24⅓ days and nights with us. This odd quarter of a day in every year makes every fourth year a leap-year to Venus; as the like does to our Earth. Her diameter is 7,906 miles; and by her diurnal motion the inhabitants about her equator are carried 43 miles every hour, besides the 69,000 above mentioned.

Her orbit lies between the Earth and Mercury.

27. Her orbit includes that of Mercury within it; for, at her greatest elongation, or apparent distance from the Sun, she is 96 times his breadth from his centre, which is almost double of Mercury's. Her orbit is included by the Earth's; for if it were not, she might be seen as often in opposition to the Sun, as she is in conjunction with him; but she was never seen 90 degrees, or a fourth part of a circle, from the Sun.

She is our morning and evening star by turns.

28. When Venus appears west of the Sun, she rises before him in the morning, and is called the morning star: when she appears east of the Sun, she shines in the evening after he sets, and is then called the evening star: being each in its turn for 290 days. It may

$23^h\ 20^m$. This result was deduced from observations made in 1667, on a bright spot in Venus's disc, which advanced 20° in the course of $24^h\ 34^m$. Cassini, reasoning no doubt from the diurnal revolution of the other planets, concluded that the spot had, during the interval of $24^h\ 34^m$ performed a complete revolution, and 20° of another, and that the rotation of the planet was complete in $23^h\ 20^m$ (Cassini. *Elémens d'Astronomie*, p. 525), while the natural conclusion should have been, that the spot had only performed part of a revolution. Signior Bianchini made similar observations in 1726, &c.; but as the spot which he observed did not make any progress in the space of three hours, he justly concluded that the spot which Cassini observed had performed only a part of a revolution, and that Venus completed her diurnal period in 24 days 8 hours. See *Hesperi et Phosphori nova phenomena*, pp. 25, 61, 63. The revolution assigned by Cassini is more analogous to that of the other planets, in none of which does the length of the day exceed 24 hours. But Bianchini's observations were more numerous, and were made at different times. The spots of Venus were shewn to several persons, who agreed as to their appearance, and these spots actually made no progress in the space of 3^h; whereas, upon Cassini's hypothesis, they ought to have advanced 45°. Notwithstanding these arguments, however, which might probably have weighed with our author, it would appear, from the observations of Schroeter, that the diurnal period assigned by Cassini is nearly true. Schroeter observed the different shapes of the two horns of Venus. He found that the one horn was pointed, while the other was blunt. The southern horn, which was at first more blunt than the northern, in two hours lost its shadow, became more pointed than the northern, and its blunted shape appeared every day about half an hour sooner, that is, after an interval of 23½ hours. This alternate bluntness and sharpness in the horns of Venus is supposed by Schroeter to arise from the shadow of a high mountain. From numerous observations, he found that Venus's diurnal revolution was performed in $23^h\ 20^m\ 59.4^s$.—*Ed.*

perhaps be surprising at first, that Venus should keep longer on the east or west of the Sun, than the whole time of her period round him. But the difficulty vanishes when we consider that the Earth is all the while going round the Sun the same way, though not so quick as Venus: and therefore her relative motion to the Earth must in every period be as much slower than her absolute motion in her orbit, as the Earth during that time advances forward in the ecliptic, which is 220 degrees. To us she appears through a telescope in all the various shapes of the Moon.[8]

29. The axis of Venus is inclined 75 degrees to the axis of her orbit, which is 51½ degrees more than our Earth's axis is inclined to the axis of the ecliptic: and therefore her seasons vary much more than ours do. The north pole of her axis inclines towards the 20th degree of Aquarius, our Earth's to the beginning of Cancer; consequently the northern parts of Venus have summer in the signs where those of our Earth have winter, and *vice versâ*.

Remarkable appearances.

30. The[9] artificial day at each pole of Venus is as long as 112½ natural days on our Earth.[1]

Her tropics and polar circles how situated.

31. The Sun's greatest declination on each side of her equator amounts to 75 degrees; therefore her[2] tropics are only 15 degrees from her poles; and her[3] polar circles as far from her equator. Consequently the tropics of Venus are between her polar circles and her poles; contrary to what those of our Earth are.

8 The line which divides the enlightened from the obscure part of Venus's disc is ragged and uneven, like that of the Moon. No bright spots have been observed on her surface since the time of Bianchini. Dr. Herschel has found her always enveloped in something resembling a white cloud, and never saw any variety in her appearance. Schroeter discovered a twilight in Venus, and supposes the denser part of her atmosphere to be 16,020 feet, or three miles nearly in height. He found, that the highest mountains of Venus as well as the moon, are in the southern hemisphere; that their perpendicular heights are as the diameter of their planets; and that one of the mountains of Venus is about 5¼ geographical miles in height, nearly six times higher than any in the moon.—*Ed.*

9 The time between the Sun's rising and setting.

1 One entire revolution, or 24 hours.

2 These are lesser circles, parallel to the equator, and as many degrees from it, towards the poles, as the axis of the planet is inclined to the axis of its orbit. When the Sun is advanced so far north or south of the equator, as to be directly over either tropic, he goes no farther, but returns towards the other.

3 These are lesser circles round the poles, and as far from them as the tropics are from the equator. The poles are the very north and south points of the planet.

The Sun's daily course

32. As her annual revolution contains only $9\frac{1}{4}$ of her days, the Sun will always appear to go through a whole sign, or twelfth part of her orbit, in a little more than three quarters of her natural day, or nearly in $18\frac{3}{4}$ of our days and nights.

and great declination.

33. Because her day is so great a part of her year, the Sun changes his declination in one day so much, that if he passes vertically, or directly over head of any given place on the tropic, the next day he will be 26° from it:[4] and whatever place he passes vertically over when in the equator, one day's revolution will remove him $36\frac{1}{4}$° from it. So that the Sun changes his declination every day in Venus about 14° more at a mean rate, than he does in a quarter of a year on our Earth. This appears to be providentially ordered, for preventing the too great effects of the Sun's heat (which is twice as great on Venus as on the Earth), so that he cannot shine perpendicularly on the same places for two days together; and on that account the heated places have time to cool.

To determine the points of the compass at her poles.

34. If the inhabitants about the north pole of Venus fix their south or meridian line through that part of the heavens where the Sun comes to his greatest height, or north declination, and call those the east and west points of their horizon which are 90° on each side from that point where the horizon is cut by the meridian line, these inhabitants will have the following remarkable appearances.

The Sun will rise $22\frac{1}{2}$° north of the east, and going on $112\frac{1}{2}$°, as measured on the plane of the horizon,[5] he will cross the meridian at an altitude of $12\frac{1}{2}$°; then making an entire revolution without setting, he will cross it again at an altitude of $48\frac{1}{2}$°; at the next revolution he will cross the meridian as he comes to his greatest height and declination, at the altitude of 75°; being then only 15° from the zenith, or that point of the heavens which is directly over head: and thence he will descend in the like spiral manner; crossing the meridian first at the altitude of $48\frac{1}{2}$°; next at the altitude of $12\frac{1}{2}$°; and going on then $112\frac{1}{2}$°, he will set $22\frac{1}{2}$° north of the west; so that after having been $4\frac{5}{8}$ revolu-

Surprising appearances at her poles.

[4] A degree is the 360th part of any circle. See § 21.

[5] The limit of any inhabitant's view, where the sky seems to touch the planet all round him.

tions above the horizon, he descends below it to exhibit the like appearances at the south pole.

35. At each pole, the Sun continues half a year without setting in summer, and as long without rising in winter; consequently the polar inhabitants of Venus have only one day and one night in the year; as it is at the poles of our Earth. But the difference between the heat of summer and cold of winter, or of mid-day and mid-night, on Venus, is much greater than on the Earth: because on Venus, as the Sun is for half a year together above the horizon of each pole in its turn, so he is for a considerable part of that time near the zenith; and during the other half of the year always below the horizon, and for a great part of that time at least 70° from it. Whereas, at the poles of our Earth, although the Sun is for half a year together above the horizon; yet he never ascends above, nor descends below it, more than 23½°. When the Sun is in the equinoctial, or in that circle which divides the northern half of the heavens from the southern, he is seen with one half of his disc above the horizon of the north pole, and the other half above the horizon of the south pole; so that his centre is in the horizon of both poles: and then descending below the horizon of one, he ascends gradually above that of the other. Hence, in a year, each pole has one spring, one harvest, a summer as long as them both, and a winter equal in length to the other three seasons.

36. At the polar circles of Venus, the seasons are much the same as at the equator, because there are only 15° between them (§ 31); only the winters are not quite so long, nor the summers so short: but the four seasons come twice round every year. At her polar circles.

37. At Venus's tropics, the Sun continues for about fifteen of our weeks together without setting in summer, and as long without rising in winter. Whilst he is more than 15 degrees from the equator, he neither rises to the inhabitants of the one tropic, nor sets to those of the other: whereas, at our terrestrial tropics, he rises and sets every day of the year. At her tropics.

38. At Venus's tropics, the seasons are much the same as at her poles; only the summers are a little longer, and the winters a little shorter.

At her equator.

39. At her equator, the days and nights are always of the same length; and yet the diurnal and nocturnal arches are very different, especially when the Sun's declination is about the greatest: for then, his meridian altitude may sometimes be twice as great as his midnight depression, and at other times the reverse. When the Sun is at his greatest declination, either north or south, his rays are as oblique at Venus's equator, as they are at London on the shortest day of winter. Therefore, at her equator there are two winters, two summers, two springs, and two autumns, every year. But because the Sun stays for some time near the tropics, and passes so quickly over the equator, every winter there will be almost twice as long as summer: the four seasons returning twice in that time, which consists only of $9\frac{1}{4}$ days.

40. Those parts of Venus which lie between the poles and tropics, and between the tropics and polar circles, and also between the polar circles and equator, partake more or less of the phenomena of these circles, as they are more or less distant from them.

Great difference of the Sun's amplitude at rising and setting.

41. From the quick change of the Sun's declination it happens, that if he rises due east on any day, he will not set due west on that day, as with us; for if the place where he rises due east be on the equator, he will set on that day almost west-north-west; or about $18\frac{1}{2}°$ north of the west. But if the place be in 45° north latitude, then on the day that the Sun rises due east he will set north-west by west, or 33° north of the west. And in 62° north latitude, when he rises in the east, he sets not in that revolution, but just touches the horizon 10° to the west of the north point: and ascends again, continuing for $3\frac{1}{4}$ revolutions above the horizon without setting. Therefore no place has the forenoon and afternoon of the same day equally long, unless it be on the equator, or at the poles.

The longitude of places easily found in Venus.

42. The Sun's altitude at noon, or any other time of the day, and his amplitude at rising and setting being very different at places on the same parallel of latitude, according to the different longitudes of those places, the longitude will be almost as easily found on Venus, as the latitude is found on the Earth: which is an advantage we can never have, because the daily change of the

Sun's declination is by much too small for that important purpos

43. On this planet, where the Sun crosses the equator in any year, he will have 9° of declination from that place on the same day and hour next year, and will cross the equator 90° farther to the west; which makes the time of the equinox a quarter of a day (or about six of our days) later every year. Hence, although the spiral in which the Sun's motion is performed be of the same sort every year, yet it will not be the very same, because the Sun will not pass vertically over the same places till four annual revolutions are finished.

Her equinoxes shift a quarter of a day forward every year.

44. We may suppose that the inhabitants of Venus will be careful to add a day to some particular part of every fourth year, which will keep the same seasons to the same days. For, as the great annual change of the equinoxes and solstices shifts the seasons a quarter of a day every year, they would be shifted through all the days of the year in 36 years. But by means of this intercalary day, every fourth year will be a leap year; which will bring her time to an even reckoning, and keep her calendar always right.

Every fourth year a leap year to Venus.

45. Venus's orbit is inclined $3\frac{1}{2}°$ to the Earth's; and crosses it in the 14° of Gemini and of Sagittarius; and therefore, when the Earth is about these points of the ecliptic at the time that Venus is in her inferior conjunction, she will appear like a spot on the Sun, and afford a more certain method of finding the distances of all the planets from the Sun than any other yet known. But these appearances happen very seldom; and will be only twice visible at London for 110 years to come. The first time will be in the year 1761, June the 6th, in the morning; and the second, on the 3d of June 1769, in the evening. Excepting such transits as these, she shews the same appearances to us regularly every eight years; her conjunctions, elongations, and times of rising and setting, being very nearly the same, on the same days, as before.

When she will appear on the Sun.

46. Venus may have a satellite or moon, although it be undiscovered by us: which will not appear very surprising, if we consider how inconveniently we are placed for seeing it;[6] for its enlightened side can

She may have a moon altho' we cannot see it.

[6] Cassini, Short, and other astronomers, imagined that they saw Venus attended with her satellite; and Lambert has given, in the Memoirs of Berlin for 1773, a theory of this secondary planet. These astronomers, however, were deceived by an

never be fully turned towards us, but when Venus is beyond the Sun; and then, as Venus appears little bigger than an ordinary star, her moon may be too small to be perceived at such a distance. When she is between us and the Sun, her full moon has its dark side towards us; and then we cannot see it any more than we can our own moon at the time of change. When Venus is at her greatest elongation, we have but one half of the enlightened side of her full moon towards us; and even then it may be too far distant to be seen by us. But if she has a moon, it may certainly be seen with her upon the Sun, in the year 1761,[7] unless its orbit be considerably inclined to the ecliptic: for if it should be in conjunction or opposition at that time, we can hardly imagine that it moves so slow as to be hid by Venus all the six hours that she will appear on the Sun's disc.[8]

The Earth. 47. The EARTH is the next planet above Venus in the system. It is 82,000,000 of miles from the Sun, and goes round him (as in the circle ⊕) in 365ᵈ 5ʰ 49ᵐ from any equinox or solstice to the same again: but from any fixed star to the same again, as seen from the Sun, in 365ᵈ 6ʰ and 9ᵐ: the former being the length of the tropical year, and the latter the length of the sydereal. It travels at the rate of 58,000 miles every hour; which motion, though 120 times swifter than that of a cannon ball, is little more than half as swift as Mercury's motion in his orbit. The earth's diameter is 7,970 miles, and by turning round its axis every 24 hours from west to east, it causes an apparent diurnal motion of all the heavenly bodies from east to west. By this rapid motion of the earth on its axis, the inhabitants about the equator are carried 1,042 miles every hour, whilst those on the parallel of London are carried only

Fig. 1.

Its diurnal and annual motion.

optical illusion, for the imaginary satellite was merely a secondary image formed by a double reflection. M. Wargentin had in his possession a good achromatic telescope, which always shewed Venus with a satellite; but the deception was discovered by moving the telescope upon its axis.—*Ed.*

[7] The transit is over since this was written, and no satellite was seen with Venus on the sun's disc.

[8] All the phenomena on the planet Venus, which depend on the time of her diurnal rotation, will be different from those mentioned by Mr. Ferguson, in consequence of his having adopted the length of her day as assigned by Bianchini; see p. 10, note. By supposing the daily revolution of Venus to be *one* of our days instead of 24, the reader may easily deduce the real phenomena seen by the inhabitants of that planet, which are affected by her diurnal revolution.—*Ed.*

about 580, besides the 58,000 miles by the annual motion above mentioned, which is common to all places whatever.

48. The Earth's axis makes an angle of $23\frac{1}{2}°$ with the axis of its orbit; and keeps always the same oblique direction, inclining towards the same fixed stars[9] throughout its annual course, which causes the returns of spring, summer, autumn, and winter; as will be explained at large in the tenth chapter. Inclination of its axis.

49. The Earth is round like a globe, as appears, 1, By its shadow in eclipses of the moon; which shadow is always bounded by a circular line (§ 314); 2, By our seeing the masts of a ship whilst the hull is hid by the convexity of the water; 3, By its having been sailed round by many navigators. The hills take off no more from the roundness of the earth, in comparison, than grains of dust do from the roundness of a common globe. A proof of its being round.

50. The seas and unknown parts of the Earth (by a measurement of the best maps) contain 160 million 522 thousand and 26 square miles; the inhabited parts 38 million 990 thousand 569, Europe 4 million 456 thousand and 65. Asia 10 million 768 thousand 823; Africa 9 million 654 thousand 807; America 14 million 110 thousand 874. In all, 199 million 512 thousand 595; which is the number of square miles on the whole surface of our globe. Its number of square miles.

51. Dr. Long, in the first volume of his astronomy, p. 168, mentions an ingenious and easy method of finding nearly what proportion the land bears to the sea; which is, to take the papers of a large terrestrial globe, and after separating the land from the sea, with a pair of scissars, to weigh them carefully in scales. This supposes the globe to be exactly delineated, and the papers all of equal thickness. The Doctor made the experiment on the papers of Mr. Senex's seventeen inch globe; and found that the sea papers weighed 349 grains, and the land only 124: by which it appears that almost three fourth parts of the surface of our Earth, between the polar circles, are covered with water, and that little more than one fourth is dry land. The Doctor omitted weighing all The proportion of land and sea.

[9] This is not strictly true, as will appear when we come to treat of the recession of the equinoctial points in the heavens, § 246; which recession is equal to the deviation of the Earth's axis from its parallelism; but this is rather too small to be sensible in an age, except to those who make very nice observations.

within the polar circles, because there is no certain measurement of the land within them, so as to know what proportion it bears to the sea.

The Moon.

52. The Moon is not a planet, but only a satellite or attendant of the Earth, going round the Earth from change to change in 29^d 12^h and 44^m; and round the Sun with it every year. The Moon's diameter is 2,180 miles, and her distance from the Earth's centre 240,000. She goes round her orbit in 27^d 7^h 43^m, moving about 2,290 miles every hour; and turns round her axis exactly in the time that she goes round the Earth, which is the reason of her keeping always the same side towards us, and that her day and night, taken together, is as long as our lunar month.

Her phases.

53. The Moon is an opaque globe like the Earth, and shines only by reflecting the light of the Sun: therefore, whilst that half of her which is towards the Sun is enlightened, the other half must be dark and invisible. Hence she disappears when she comes between us and the Sun, because her dark side is then towards us. When she is gone a little way forward, we see a little of her enlightened side: which still increases to our view, as she advances forward, until she comes to be opposite to the Sun; and then her whole enlightened side is towards the Earth, and she appears with a round illumined orb, which we call the *full moon*: her dark side being then turned away from the Earth. From the full she seems to decrease gradually as she goes through the other half of her course, shewing us less and less of her enlightened side every day, till her next change or conjunction with the Sun, and then she disappears as before.

A proof that she shines not by her own light.

54. This continual change of the Moon's phases demonstrates that she shines not by any light of her own: for if she did, being globular, we should always see her with a round full orb like the Sun.

Fig. 1.

Her orbit is represented in the scheme by the little circle *m*, upon the Earth's orbit ⊕: but it is drawn fifty times too large in proportion to the Earth's; and yet is almost too small to be seen in the diagram.

One half of her always enlightened.

55. The Moon has scarcely any difference of seasons, her axis being almost perpendicular to the ecliptic. What is very singular, one half of her has no darkness at all, the Earth constantly affording it a strong

light in the Sun's absence; while the other half has a fortnight's darkness and a fortnight's light by turns.

56. Our Earth is a Moon to the Moon, waxing and waning regularly, but appearing thirteen times as big, and affording her thirteen times as much light as she does to us. When she changes to us, the Earth appears full to her; and when she is in her first quarter to us, the Earth is in its third quarter to her; and *vice versâ*.

Our Earth is her Moon.

57. But from one half of the Moon, the Earth is never seen at all:[1] from the middle of the other half it is always seen over head, turning round almost thirty times as quick as the Moon does. From the circle which limits our view of the Moon, only one half of the Earth's side next her is seen, the other half being hid below the horizon of all places on that circle. To her the Earth seems to be the biggest body in the universe, for it appears thirteen times as big as she does to us.

58. The Moon has no atmosphere of any visible density surrounding her as we have: for if she had, we could never see her edge so well defined as it appears; but there would be a sort of a mist or haziness around her, which would make the stars look fainter, when they are seen through it.[2] But observation proves, that the stars which disappear behind the Moon retain their full lustre until they seem to touch her very edge, and then they

A proof of the Moon's having no atmosphere.

[1] This is not exactly the case, for we sometimes see a portion of the Moon's eastern hemisphere, which was not seen in a former part of her revolution, and lose sight of a similar portion of the Moon's western limb. The *Crisian sea*, for example, which is a large dark spot on the western side of the moon, is sometimes ⅔ of its diameter from her limb, and at other times so near it, that the interval can scarcely be observed. See the Supplementary chapter, on Selenography.—*Ed.*

[2] Astronomers have long been divided in opinion respecting the atmosphere of the Moon. Those who deny its existence, argue chiefly from the appearance of fixed stars, that emerge behind the moon's limb, without losing their usual lustre. But if we consider, that the lunar atmosphere, if it did exist, could not subtend an angle of more than one second, and that the emerging star moves through this space in *two seconds* of time, we can scarcely expect to perceive any considerable change in its brilliancy. Besides, if the star emerges at a part of the Moon's limb where there is a ridge of mountains, the time during which its lustre should be observed, would be much less than two seconds, and sometimes imperceptible. On this point, however, we are not left to vague conjecture, for M. Schroeter has discovered, near the Moon's cusps, a faint grey light, of a pyramidal form, which, being the Moon's twilight, must necessarily arise from her atmosphere. M. Schroeter concludes, from his observations, that the height of the Moon's atmosphere, where it could diminish the brightness of a star, or inflect the rays of light, does not exceed 5742 feet. See chap. xv, note 2.—*Ed.*

vanish in a moment. This has been often observed by astronomers, but particularly by Cassini,[3] of the star γ, in the breast of Virgo, which appears single and round to the bare eye; but through a refracting telescope of 16 feet, appears to be two stars so near together, that the distance between them seems to be but equal to one of their apparent diameters. The Moon was observed to pass over them on the 21st of April 1720, N.S. and as her dark edge drew near to them, it caused no change in their colour or situation. At 25^m 14^s past 12 at night, the most westerly of these stars was hid by the dark edge of the Moon; and in 30^s afterwards, the most easterly star was hid: each of them disappearing behind the Moon in an instant, without any preceding diminution of magnitude or brightness; which by no means could have been the case if there were an atmosphere round the Moon; for then, one of the stars, falling obliquely into it before the other, ought by refraction to have suffered some change in its colour, or in its distance from the other star, which was not yet entered into the atmosphere. But no such alteration could be perceived, though the observation was performed with the utmost attention to that particular; and was very proper to have made such a discovery The faint light, which has been seen all around the Moon, in total eclipses of the Sun, has been observed, during the time of darkness, to have its centre coincident with the centre of the Sun; and was, therefore, much more likely to arise from the atmosphere of the Sun, than from that of the Moon; for if it had been owing to the latter, its centre would have gone along with the moon's.

Nor seas.

59. If there were seas in the Moon, she could have no clouds, rains, nor storms, as we have; because she has no such atmosphere to support the vapours which occasion them. And every one knows, that when the Moon is above our horizon in the night-time, she is visible, unless the clouds of our atmosphere hide her from our view; and all parts of her appear constantly with the same clear, serene, and calm aspect. But those dark parts of the Moon, which were formerly thought to be seas, are now found to be only vast deep cavities, and places which reflect not the Sun's light so strongly as others, having many caverns

She is full of caverns and deep pits.

[3] *Mémoires de l'Acad. Par.* 1720.

and pits, whose shadows fall within them, and are always dark on the sides next the Sun, which demonstrates their being hollow; and most of these pits have little knobs like hillocks standing within them, and casting shadows also, which cause these places to appear darker than others that have fewer or less remarkable caverns. All these appearances shew that there are no seas in the Moon; for if there were any, their surfaces would appear smooth and even, like those on the Earth.[4]

60. There being no atmosphere about the Moon, the heavens in the day-time have the appearance of night to a lunarian who turns his back toward the Sun; and when he does, the stars appear as bright to him as they do in the night to us. For, it is entirely owing to our atmosphere that the heavens are bright about us in the day.

The stars always visible to the Moon.

61. As the Earth turns round its axis, the several continents, seas, and islands appear to the Moon's inhabitants like so many spots, of different forms and brightness, moving over its surface; but much fainter at some times than others, as our clouds cover them or leave them. By these spots the lunarians can determine the time of the Earth's diurnal motion, just as we do the motion of the Sun; and perhaps they measure their time by the motion of the Earth's spots, for they cannot have a truer dial.

The Earth a dial to the Moon.

62. The Moon's axis is so nearly perpendicular to the ecliptic, that the Sun never removes sensibly from her equator; and the obliquity[5] of her orbit, which is next to nothing, as seen from the Sun, cannot cause the Sun to decline sensibly from her

[4] The arguments adduced by Mr. Ferguson to prove that there is no sea in the moon, are very far from being conclusive. The existence of a lunar atmosphere is completely ascertained; and the little pits and eminences which appear in the dark parts of the moon, which are extremely even and smooth, may be regarded as rocks or islands. By observations, however, on the *Mare Crisium*, when the line which separates the enlightened from the obscure segment of the Moon passed through this large and apparently level spot, I have found that the shaded parts of the Moon, however smooth they may appear, are not level surfaces, and therefore cannot be seas. If there were seas in the Moon, there would be particular times when the reflected light of the Sun would render them more brilliant than any other part of her surface, and the light would acquire that property called *polarisation*, which is however found not to be the case. These facts will be stated more fully in the Supplement.—*Ed.*

[5] The Moon's orbit crosses the ecliptic in two opposite points, called the moon's nodes; so that one half of her orbit is above the ecliptic, and the other half below it. The angle of its obliquity is 5½ degrees.

How the lunarians may know the length of their year,

equator. Yet her inhabitants are not destitute of means for ascertaining the length of their year, though their method and ours must differ: for we can know the length of our year by the return of our equinoxes; but the lunarians, having always equal day and night, must have recourse to another method; and we may suppose, they measure their year by observing when either of the poles of our Earth begins to be enlightened, and the other to disappear, which is always at our equinoxes; they being conveniently situated for observing great tracts of land about our earth's poles, which are entirely unknown to us. Hence we may conclude, that the year is of the same absolute length both to the Earth and Moon, though very different as to the number of days; we having $365\frac{1}{4}$ natural days, and the lunarians only $12\frac{7}{19}$; every day and night in the Moon being as long as $29\frac{1}{2}$ on the Earth.

and the longitudes of their places.

63. The Moon's inhabitants on the side next the Earth may as easily find the longitude of their places as we can find the latitude of ours, for the Earth keeping constantly, or very nearly so, over one meridian of the Moon, the east or west distances of places from that meridian are as easily found, as we can find our distance from the equator by the altitude of our celestial poles.

Mars.

64. The planet MARS is next in order, being the first above the Earth's orbit. His distance from the Sun is computed to be 125,000,000 of miles; and by travelling at the rate of 47,000 miles every hour, as in the circle ♂, he goes round the Sun in 686 of our days and 23 hours, which is the length of his year, and contains $667\frac{3}{4}$ of his days; every day and night together being 40 minutes longer than with us. His diameter is 4,444 miles; and by his diurnal rotation the inhabitants about his equator are carried 556 miles every hour. His quantity of light and heat is equal but to one half of ours; and the Sun appears but half as big to him as to us.

Fig. 1.

65. This planet being but a fifth part so big as the Earth, if any moon attends him, she must be very small, and has not yet been discovered by our best telescopes. He is of a fiery red colour, and by his appulses to some of the fixed stars, seems to be encompassed by a very gross atmosphere. He appears sometimes gibbous, but ne-

His atmosphere and phases.

ver horned, which both shews that his orbit includes the Earth's within it, and that he shines not by his own light.

66. To Mars, our Earth and Moon appear like two Moons, a bigger and a less; changing places with one another, and appearing sometimes horned, sometimes half or three quarters illuminated, but never full; nor at most above one quarter of a degree from each other, although they are 24,000 miles asunder.

How the other planets appear to Mars.

67. Our Earth appears almost as big to Mars as Venus does to us, and at Mars it is never seen above 48° from the Sun; sometimes it appears to pass over the disc of the Sun, and so do Mercury and Venus; but Mercury can never be seen from Mars by such eyes as ours, unassisted by proper instruments; and Venus will be as seldom seen as we see Mercury. Jupiter and Saturn are as visible to Mars as to us. His axis is perpendicular to the ecliptic, and his orbit is two degrees inclined to it.[6]

Jupiter.

68. JUPITER,[7] the biggest of all the planets, is still higher in the system, being about 426 millions of miles from the Sun: and, going at the rate of 25,000 miles every hour in his orbit, as in the circle ♃, finishes his annual period in eleven of our years 314 days and 12 hours. He is above 1000 times as big as the Earth, for his diameter is 81,000 miles; which is more than ten times the diameter of the Earth.

Fig. 1.

The number of days in his year.

69. Jupiter turns round his axis in 9 hours 56 minutes, so that his year contains 10,470 days; and the diurnal velocity of his equatorial parts is greater than the swiftness with which he moves in his annual orbit; a singular circumstance as far as we know. By this prodigious quick rotation, his equatorial inhabitants are carried 25,920 miles every hour, (which is 920 miles an hour more than an inhabitant of our Earth's equator moves in 24 hours), besides the 25,000 above mentioned, which is common to all parts of his surface, by his annual motion.

[6] About the commencement of the present century, within the space of a few years, four new planets, CERES, PALLAS, JUNO, and VESTA, have been added to the solar system. They are placed between the orbits of Mars and Jupiter, and differ from the other bodies of the system in their size and appearance, as well as in the form and position of their orbits. See the Supplementary Chapter, on the New Planets.—*Ed.*

[7] See the Supplementary Chapter, on the Discoveries respecting Jupiter and Saturn, &c.—*Ed.*

His belts and spots. 70. Jupiter is surrounded by faint substances, called belts, in which so many changes appear, that they are generally thought to be clouds; for some of them have been first interrupted and broken, and then have vanished entirely. They have sometimes been observed of different breadths, and afterwards have all become nearly of the same breadth. Large spots have been seen in these belts; and when a belt vanishes, the contiguous spots disappear with it. The broken ends of some belts have been generally observed to revolve in the same time with the spots, only those nearer the equator in somewhat less time than those near the poles; perhaps on account of the Sun's greater heat near the equator, which is parallel to the belts and course of the spots. Several large spots, which appear round at one time, grow oblong by degrees, and then divide into two or three round spots. The periodical time of the spots near the equator is $9^h\ 50^m$, but of those near the poles, $9^h\ 56^m$. See Dr. Smith's Optics, § 1004, *et seq.*

He has no change of seasons; 71. The axis of Jupiter is so nearly perpendicular to his orbit, that he has no sensible change of seasons; which is a great advantage, and wisely ordered by the Author of nature: for, if the axis of this planet were inclined any considerable number of degrees, just so many degrees round each pole would in their turn be almost six of our years together in darkness. And, as each degree of a great circle on Jupiter contains 706 of our miles at a mean rate, it is easy to judge what vast tracts of land would be rendered uninhabitable by any considerable inclination of his axis

72. The Sun appears but $\frac{1}{28}$ part so big to Jupiter as to us; and his light and heat are in the same small proportion, but but has four moons. compensated by the quick returns thereof, and by four moons (some bigger and some less than our Earth) which revolve about him: so that there is scarce any part of this huge planet but what is during the whole night enlightened by one or more of these moons, except his poles, whence only the farthest moons can be seen, and where light is not there wanted, because the Sun constantly circulates in or near the horizon, and is very probably kept in view of both poles by the refraction of Jupiter's atmosphere, which, if it be like ours, has certainly refractive power enough for that purpose.

Their periods round Jupiter.

73. The orbits of these moons are represented in the scheme of the solar system by four small circles marked 1, 2, 3, 4, on Jupiter's orbit ♃; but they are drawn fifty times too large in proportion to it. The first moon, or that nearest to Jupiter, goes round him in 1^d 18^h and 36^m of our time, and is 229,000 miles distant from his centre: the second performs its revolution in 3^d 13^h and 15^m, at 364,000 miles distance: the third in 7^d 3^h and 59^m, at the distance of 580,000 miles: and the fourth, or outermost, in 16^d 18^h and 30^m, at the distance of 1,000,000 of miles from his centre.

Parallax of their orbits, and distances from Jupiter. How he appears to his nearest moon.

74. The angles under which the orbits of Jupiter's moons are seen from the Earth, at its mean distance from Jupiter, are as follow: The first, 3′ 5″; the second, 6′ 14″; the third, 9′ 58″; and the fourth, 17′ 30″. And their distances from Jupiter, measured by his semidiameters, are thus: The first, $5\frac{2}{3}$; the second. 9; the third, $14\frac{23}{60}$; and the fourth, $25\frac{18}{60}$.[8] This planet, seen from its nearest moon, appears 1000 times as large as our Moon does to us, waxing and waning in all her monthly shapes every $42\frac{1}{2}$ hours.

Two grand discoveries made by the eclipse of Jupiter's moons.

75. Jupiter's three nearest moons fall into his shadow, and are eclipsed in every revolution: but the orbit of the fourth moon is so much inclined, that it passeth by its opposition to Jupiter, without falling into his shadow, two years in every six. By these eclipses, astronomers have not only discovered that the Sun's light takes up eight minutes of time in coming to us; but they have also determined the longitudes of places on this Earth with greater certainty and facility than by any other method yet known, as shall be explained in the eleventh chapter.

The great difference between the equatorial and polar diameters of Jupiter.

76. The difference between the equatorial and polar diameters of Jupiter is 6230 miles; for his equatorial diameter is to his polar, as 13 to 12; so that his poles are 3115 miles nearer his centre than his equator is. This results from his quick motion round his axis; for the fluids, together with the light particles, which they can carry or wash away with them, recede from the poles which are at rest, towards the equator, where the motion is quickest, until there be a sufficient number

[8] Cassini *Elémens d'Astronomie*, liv. ix, chap. 3.

accumulated to make up the deficiency of gravity occasioned by the centrifugal force, which always arises from a quick motion round an axis: and when the deficiency of weight or gravity of the particles is made up by a sufficient accumulation, there is an equilibrium, and the equatorial parts rise no higher.

The difference little in those of our Earth.

Our Earth being but a very small planet compared to Jupiter, and its motion on its axis being much slower, it is less flattened of course; for the difference between its equatorial and polar diameters is only as 230 to 229, namely, 36 miles.[9]

Place of his nodes.

77. Jupiter's orbit is 1° 20′ inclined to the ecliptic. His north node is in the 7° of Cancer, and his south node in the 7° of Capricorn.

Saturn.

78. SATURN,[1] the most remarkable of all the planets, is about 780,000,000 of miles from the Sun; and, travelling at the rate of 18,000 miles every hour, as in the circle marked ♄, performs its annual circuit in 29^y 167^d and 5^h of our time, which makes only one year to that planet. Its diameter is 67,000 miles, and therefore it is near 600 times as big as the Earth.

Fig. 1.

Plate I, Fig. 5. His ring.

79. This planet is surrounded by a thin broad ring, as an artificial globe is by a horizon. The ring appears double when seen through a good telescope, and is represented by the figure in such an oblique view as it is generally seen. It is inclined 30° to the ecliptic, and is about 21,000 miles in breadth, which is equal to its distance from Saturn on all sides. There is reason to believe that the ring turns round its axis, because, when it is almost edgeways to us, it appears somewhat thicker on one side of the planet than on

[9] According to the French measures, a degree of the meridian at the equator contains 340,606.68 French feet; and a degree of the meridian in Lapland contains 344,627.40: so that a degree in Lapland is 4,020.72 French feet (or 4,280.02 English feet) longer than a degree at the equator. The difference is $\frac{81}{100}$ parts of an English mile. Hence, the earth's equatorial diameter contains 39,386,196 French feet, or 41,926,356 English, and the polar diameter 39,202,920 French feet, or 41,731,272 English.* So that the equatorial diameter is 195,084 English feet, 36,948 English miles longer than the axis.

[1] See the Supplementary chapter in Vol. ii, on the new discoveries concerning Jupiter and Saturn, &c.

* From a comparison of the length of different degrees of the meridian lately measured, it appears that the compression at the Earth's poles is only 1-300th; and since the diameter of the earth at the equator is 7,934 English miles, its diameter at the poles will be 7,908 miles, and the difference between these diameters 26 miles.—*Ed.*

the other; and the thickest edge has been seen on different sides at different times. But Saturn having no visible spots on his body, whereby to determine the time of his turning round his axis, the length of his days and nights, and the position of his axis, are unknown to us.

80. To Saturn, the Sun appears only $\frac{1}{90}$th part so big as to us, and the light and heat he receives from the Sun are in the same proportion to ours. But to compensate for the small quantity of sun-light, he has five moons, all going round him on the outside of his ring, and nearly in the same plane with it. The first, or nearest moon to Saturn, goes round him in $1^{d}\ 21^{h}\ 19^{m}$, and is 140,000 miles from his centre: the second, in $2^{d}\ 17^{h}\ 40^{m}$, at the distance of 187,000 miles: the third, in $4^{d}\ 12^{h}\ 25^{m}$, at 263,000 miles distance: the fourth, in $15^{d}\ 22^{h}\ 41^{m}$, at the distance of 600,000 miles: and the fifth, or outermost, at 1,800,000 miles from Saturn's centre, goes round him in $79^{d}\ 7^{h}\ 48^{m}$. Their orbits in the scheme of the solar system are represented by the five small circles, marked 1, 2, 3, 4, 5, on Saturn's orbit; but these, like the orbits of the other satellites, are drawn fifty times too large in proportion to the orbits of their primary planets. His five moons. Fig. 1.

81. The Sun shines almost 15 of our years together on one side of Saturn's ring without setting, and as long on the other in its turn; so that the ring is visible to the inhabitants of that planet for almost 15 of our years, and as long invisible by turns, if its axis has no inclination to its ring; but if the axis of the planet be inclined to the ring, suppose about 30°, the ring will appear and disappear once every natural day to all the inhabitants within 30° of the equator, on both sides, frequently eclipsing the Sun in a Saturnian day. Moreover, if Saturn's axis be so inclined to his ring, it is perpendicular to his orbit, and thereby the inconvenience of different seasons to that planet is avoided;[2] for, considering the length of Saturn's year, which is almost equal to 30 of ours, what a dreadful condition must the inhabitants of his polar regions be in, if they be half that time deprived of the light and heat of the Sun? which is not their case alone, if the axis of the His axis probably inclined to his ring.

[2] The axis of Saturn is perpendicular to the plane of his double ring, which revolves along with the planet in $10^{h}\ 16^{m}\ 2^{s}$.—*Ed.*

planet be perpendicular to the ring, for then the ring must hide the sun from vast tracts of land on each side of the equator for 13 or 14 of our years together, on the south side and north side by turns, as the axis inclines to or from the Sun: the reverse of which inconvenience is another good presumptive proof of the inclination of Saturn's axis to its ring, and also of his axis being perpendicular to his orbit.

How the ring appears to Saturn and to us.

82. This ring, seen from Saturn, appears like a vast luminous arch in the heavens, as if it did not belong to the planet. When we see the ring most open, its shadow upon the planet is broadest; and from that time the shadow grows narrower, as the ring appears to do to us; until, by Saturn's annual motion, the Sun comes to the plane of the ring, or even with its edge; which being then directed towards us, becomes invisible on account of its thinness, as shall be explained more largely in the tenth chapter, and illustrated by a figure. The ring disappears twice in every annual revolution of Saturn, namely, when he is in the 19° both of Pisces and of Virgo. And when Saturn is in the middle between these points, or in the 19° either of Gemini or of Sagittarius, his ring appears most open to us; and then its longest diameter is to its shortest, as 9 to 4.

In what signs Saturn appears to lose his ring, and to what signs it appears most open to us.

No planet but Saturn can be seen from Jupiter, nor any from Saturn besides Jupiter.

83. To such eyes as ours, unassisted by instruments, Jupiter is the only planet that can be seen from Saturn, and Saturn the only planet that can be seen from Jupiter; so that the inhabitants of these two planets must either see much farther than we do, or have equally good instruments to carry their sight to remote objects, if they know that there is such a body as our Earth in the universe: for the Earth is no bigger seen from Jupiter, than his moons are seen from the Earth; and if his large body had not first attracted our sight, and prompted our curiosity to view him with a telescope, we should never have known any thing of his moons, unless by chance we had directed the telescope toward that small part of the heavens where they were at the time of observation. And the like is true of the moons of Saturn.

Place of Saturn's nodes.

84. The orbit of Saturn is $2\frac{1}{2}$° inclined to the ecliptic, or orbit of our Earth, and intersects it in

the 21° of Cancer and of Capricorn; so that Saturn's nodes are only 14° from Jupiter's, § 77.[3]

85. The quantity of light afforded by the Sun to Jupiter being but $\frac{1}{28}$ part, and to Saturn only $\frac{1}{90}$ part, of what we enjoy; may at first thought induce us to believe that these two planets are entirely unfit for rational beings to dwell upon. But, that their light is not so weak as we imagine, is evident from their brightness in the night-time; and also from this remarkable phenomenon, that when the Sun is so much eclipsed to us, as to have only the 40th part of his disc left uncovered by the Moon, the decrease of light is not very sensible: and just at the end of darkness in total eclipses, when his western limb begins to be visible, and seems no bigger than a bit of fine silver wire, every one is surprised at the brightness wherewith that small part of him shines. The Moon, when full, affords travellers light enough to keep them from mistaking their way; and yet, according to Dr. Smith,[4] it is equal to no more than a 90,000th part of the light of the Sun: that is, the Sun's light is 90,000 times as strong as the light of the moon when full. Consequently the Sun gives 1000 times as much light to Saturn as the full moon does to us, and above 3000 times as much to Jupiter; so that these two planets, even without any moons, would be much more enlightened than we at first imagine; and by having so many, they may be very comfortable places of residence. Their heat, so far as it depends on the force of the Sun's rays, is certainly much less than ours, to which no doubt the bodies of their inhabitants are as well adapted as ours are to the seasons we enjoy. And if we consider, that Jupiter never has any winter, even at his poles, which probably is also the case with Saturn, the cold cannot be so intense on these two planets as is generally imagined. Besides, there may be something in the nature of their mould warmer than in that of our Earth: and we find that all our heat depends not on the rays of the Sun; for if it did, we should always have the same months equally hot or cold at their annual returns.

The Sun's light much stronger on Jupiter and Saturn than is generally believed.

All our heat depends not on the Sun's rays.

[3] In the year 1781, Dr. Herschel discovered a new planet, without the orbit of Saturn, and called it the *Georgium Sidus*, in honour of his late majesty. A full account of this discovery will be found in the Supplementary chapter on the New Planets.—*Ed.*

[4] Optics, Art. 95.

But it is far otherwise, for February is sometimes warmer than May; which must be owing to vapours and exhalations from the earth.

86. Every person who looks upon and compares the systems of moons together, which belong to Jupiter and Saturn, must be amazed at the vast magnitude of these two planets, and the noble attendance they have in respect of our little Earth; and can never bring himself to think, that an infinitely wise creator should dispose of all his animals and vegetables here, leaving the other planets bare and destitute of rational creatures. To suppose that he had any view to our benefit, in creating these moons, and giving them their motions round Jupiter and Saturn; to imagine that he intended these vast bodies for any advantage to us, when he well knew that they could never be seen but by a few astronomers peeping through telescopes; and that he gave to the planets regular returns of days and nights, and different seasons to all where they would be convenient, but of no manner of service to us, except only what immediately regards our own planet the Earth; to imagine, I say, that he did all this on our account, would be charging him impiously with having done much in vain: and as absurd, as to imagine that he has created a little sun and a planetary system within the shell of our Earth, and intended them for our use. These considerations amount to little less than a positive proof, that all the planets are inhabited: for if they are not, why all this care in furnishing them with so many moons, to supply those with light which are at the greater distances from the Sun? Do we not see, that the farther a planet is from the Sun, the greater apparatus it has for that purpose? save only Mars, which being but a small planet, may have moons too small to be seen by us. We know that the Earth goes round the Sun, and turns round its own axis, to produce the vicissitudes of summer and winter by the former, and of day and night by the latter motion, for the benefit of its inhabitants. May we not then fairly conclude, by parity of reason, that the end and design of all the other planets is the same? and is not this agreeable to the beautiful harmony which exists throughout the universe? Surely it is; and raises in us the most magnificent ideas of the Supreme Being, who is everywhere, and at all times present; displaying his power, wisdom, and goodness, among all his

It is highly probable that all the planets are inhabited.

creatures! and distributing happiness to innumerable ranks of various beings!

87. In Fig. 2, we have a view of the proportional breadth of the Sun's face or disc, as seen from the different planets. The Sun is represented No. 1, as seen from Mercury; No. 2, as seen from Venus; No. 3, as seen from the Earth; No. 4, as seen from Mars; No. 5, as seen from Jupiter; and No. 6, as seen from Saturn.

Fig. 2. How the Sun appears to different planets.

Let the circle *B* be the Sun as seen from any planet at a given distance; to another planet, at double that distance, the Sun will appear just of half that breadth, as *A*; which contains only one fourth part of the area or surface of *B*. For, all circles, as well as square surfaces, are to one another as the squares of their diameters. Thus, the square *A* is just half as broad as the square *B*; and yet it is plain to sight, that *B* contains four times as much surface as *A*. Hence, by comparing the diameters of the above circles (Fig. 2) together, it will be found, that in round numbers, the Sun appears seven times larger to Mercury than to us, 90 times larger to us than to Saturn, and 630 times as large to Mercury as to Saturn.

Fig. 3.

Fig. 4.

88. In Fig. 5, we have a view of the bulks of the planets in proportion to each other, and to a supposed globe of two feet diameter for the Sun. The Earth is 27 times as big as Mercury, very little bigger than Venus, 5 times as big as Mars; but Jupiter is 1049 times as big as the Earth, Saturn 586 times as big, exclusive of his ring; and the Sun is 877,650 times as big as the Earth. If the planets in this figure were set at their due distances from a sun of two feet diameter, according to their proportional bulks, as in our system, Mercury would be 28 yards from the Sun's centre; Venus, 51 yards 1 foot; the Earth, 70 yards 2 feet; Mars, 107 yards 2 feet; Jupiter, 370 yards 2 feet; and Saturn, 760 yards 2 feet; the comet of the year 1680, at its greatest distance, 10,760 yards. In this proportion, the Moon's distance from the centre of the Earth would be only 7½ inches.

Fig. 5. Proportional bulks and distances of the planets.

89. To assist the imagination in forming an idea of the vast distances of the Sun, planets, and stars, let us suppose, that a body projected from the Sun should continue to fly with the swiftness of a cannon-ball, *i. e.* 480 miles every hour; this body would reach the orbit of Mer-

An idea of their distances.

cury in 7 years 221 days; of Venus, in 14 years 8 days; of the Earth, in 19 years 91 days; of Mars, in 29 years 85 days; of Jupiter, in 100 years 280 days; of Saturn, in 184 years 240 days; to the comet of 1680, at its greatest distance from the sun, in 2660 years; and to the nearest fixed stars in about 7,600,000 years.

Why the planets appear bigger and less at different times.

90. As the Earth is not in the centre of the orbits in which the planets move, they come nearer to it and go farther from it at different times; on which account they appear bigger and less by turns. Hence, the apparent magnitudes of the planets are not always a certain rule to know them by.[5]

91. Under Fig. 3, are the names and characters of the 12 signs of the zodiac, which the reader should be perfectly well acquainted with, so as to know the characters without seeing

Fig. 1.

the names. Each sign contains 30°, as in the circle bounding the solar system, to which the characters of the signs are set in their proper places

The comets.

92. The COMETS are solid opaque bodies with long transparent trains or tails, issuing from that side which is turned away from the Sun.[6] They move about the sun in very eccentric ellipses, and are of a much greater density than the Earth; for some of them are heated in every period to such a degree, as would vitrify or dissipate any substance known to us. Sir Isaac Newton computed the heat of the comet which appeared in the year 1680, when nearest the Sun, to be 2000 times hotter than red hot iron, and that being thus heated, it must retain its heat until it comes round again, although its period should be more than 20,000 years; and it is computed to be only 575. The method of computing the heat of bodies, keeping at any known distance from the Sun, so far as their heat depends on the force of the Sun's rays, is very easy; and shall be explained in the eighth chapter.

[5] The planets may be distinguished from one another by their difference of colour, and some of them by their position with regard to the Sun. The planet Venus emits a beautiful white light; she twinkles when she is not far from the Sun, and can never be seen above three or four hours after sun-set; she is therefore to be looked for in the western part of the horizon after the Sun sets, or in the eastern part of it before he rises. Mars is of a red fiery colour, and apparently not so large as Venus and Jupiter. Jupiter shines with a white light, but is not so bright as Venus. Saturn appears less than Jupiter, and is of a dark red colour, but not so brilliant as Mars.—*Ed.*

[6] See the Supplementary chapter on Comets.—*Ed.*

93. Part of the paths of three comets are delineated in the scheme of the solar system, and the years marked in which they made their appearance. It is believed that there are at least 21 comets belonging to our system, moving in all sorts of directions: and all those which have been observed, have moved through the ethereal regions, and the orbits of the planets, without suffering the least sensible resistance in their motions; which plainly proves that the planets do not move in solid orbs. Of all the comets, the periods of the above mentioned three only are known with any degree of certainty. The first of these comets appeared in the years 1531, 1607, and 1682; and is expected to appear again in the year 1758, and every 75th year afterwards. The second of them appeared in 1532 and 1661, and may be expected to return in 1789, and every 129th year afterwards. The third, having last appeared in 1680, and its period being no less than 575 years, cannot return until the year 2225. This comet, at its greatest distance, is about 11,200,000,000 of miles from the Sun; and at its least distance from the Sun's centre, which is 49,000 miles, is within less than a third part of the sun's semidiameter from the surface. In that part of its orbit which is nearest the sun, it flies with the amazing swiftness of 880,000 miles in an hour; and the Sun, as seen from it, appears 100° in breadth; consequently 40,000 times as large as he appears to us. The astonishing length that this comet runs out into empty space, suggests to our minds an idea of the vast distance between the Sun and the nearest fixed stars; of whose attractions all the comets must keep clear, to return periodically, and go round the Sun; and it shews us also, that the nearest stars, which are probably those that seem the largest, are as big as our Sun, and of the same nature with him; otherwise they could not appear so large and bright to us as they do at such an immense distance.

Plate I, Fig. 1.

They prove that the orbits of the planets are not solid.

The periods only of three are known.

They prove the stars to be at immense distances.

94. The extreme heat, the dense atmosphere, the gross vappurs, the chaotic state of the comets, seem at first sight to indicate them altogether unfit for the purposes of animal life, and a most miserable habitation for rational beings; and therefore some[7] are of opinion

Inferences drawn from the above phenomena.

[7] Mr. Whiston, in his *Astronomical Principles of Religion.*

that they are so many hells for tormenting the damned with perpetual vicissitudes of heat and cold. But when we consider, on the other hand, the infinite power and goodness of the Deity; the latter inclining, the former enabling, him to make creatures suited to all states and circumstances; that matter exists only for the sake of intelligent beings; and that wherever we find it, we always find it pregnant with life, or necessarily subservient thereto; the numberless species, the astonishing diversity of animals in earth, air, water, and even on other animals; every blade of grass, every tender leaf, every natural fluid, swarming with life; and every one of these enjoying such gratifications as the nature and state of each requires. When we reflect, moreover, that, some centuries ago, till experience undeceived us, a great part of the Earth was judged uninhabitable; the torrid zone, by reason of excessive heat, and the two frigid zones, because of their intolerable cold; it seems highly probable, that such numerous and large masses of durable matter as the comets are, however unlike they be to our Earth, are not destitute of beings capable of contemplating with wonder, and acknowledging with gratitude, the wisdom, symmetry, and beauty, of the creation; which is more plainly to be observed in their extensive tour through the heavens, than in our more confined circuit. If farther conjecture is permitted, may we not suppose them instrumental in recruiting the expended fuel of the Sun, and supplying the exhausted moisture of the planets? However difficult it may be, circumstanced as we are, to find out their particular destination, this is an undoubted truth, that wherever the Deity exerts his power, there he also manifests his wisdom and goodness.

This system very ancient, and demonstrable.

95. The solar system here described is not a late invention; for it was known and taught by the wise Samian philosopher Pythagoras, and others among the ancients: but in latter times was lost, till the 15th century, when it was again restored by the famous Polish philosopher, Nicolaus Copernicus, who was born at Thorn in the year 1473. In this, he was followed by the greatest mathematicians and philosophers that have since lived; as Kepler, Galileo, Descartes, Gassendus, and Sir Isaac Newton; the last of whom has established this system on such an everlasting foundation of mathematical and physical demonstration, as can never be shaken: and none who understand him can hesitate about it.

The Ptolemean system absurd.

96. In the Ptolemean system, the Earth was supposed to be fixed in the centre of the universe; and that the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, moved round the earth: above the planets, this hypothesis placed the firmament of stars, and then the two chrystalline spheres; all which were included in and received motion from the *primum mobile*, which constantly revolved about the earth in 24 hours from east to west. But as this rude scheme was found incapable to stand the test of art and observation, it was soon rejected by all true philosophers; notwithstanding the opposition and violence of blind and zealous bigots.

The Tychonic system, partly true and partly false.

97. The Tychonic system succeeded the Ptolemean system, but was never so generally received. In this the Earth was supposed to stand still in the centre of the universe or firmament of stars, and the sun to revolve about it every 24 hours; the planets, Mercury, Venus, Mars, Jupiter, and Saturn, going round the Sun in the times already mentioned. But some of Tycho's disciples supposed the earth to have a diurnal motion round its axis, and the Sun, with all the above planets, to go round the Earth in a year; the planets moving round the Sun in the foresaid times. This hypothesis, being partly true and partly false, was embraced by few; and soon gave way to the only true and rational system, restored by Copernicus, and demonstrated by Sir Isaac Newton.*

98. To bring the foregoing particulars at once in view, with several others which follow, concerning the periods, distances, bulks, &c. of the planets, the following table is inserted.

* Longomontanus, the friend and disciple of Tycho, supported a hypothesis different from these, and approaching nearer than the rest to the system of Copernicus. He maintained with Ptolemy, that the Earth was the centre of the universe; and with Tycho, that all the planets revolved round the Sun, placed in one of the foci of their elliptical orbits: but he held with Copernicus, that the diurnal motion of the heavenly bodies arose from the rotation of the Earth upon its axis, and thus got rid of one of the strongest objections to the system of his friend and master. This system explains, in a satisfactory manner, all the general astronomical phenomena.—*Ed.*

A TABLE of the Periods, Revolutions, Magnitudes, &c. of the Planets, as formerly computed by Astronomers. For their nearly true distances from the Sun, as determined from observations of the transit of Venus, in the year 1761, see § 194.

Sun and planets.	Annual period round the Sun.	Diurnal rotation on its axis.	Diameter in English miles.	Mean diam. as seen fr. the Sun.	Mean distance from the Sun in Eng. miles.	Eccentricity of its orbit in miles.	Axis inclined to orbit.	Orbit inclined to ecliptic.	Place of its aphelion.	Place of its ascending node.	Proportion of diameters.	Proportion of bulk.	Prop. of gravity on the surface.	Proportion of density.
Sun		25d 6h	763,000				8° 0′				10 000	877,650	24	25 1/2
Mercury	87d 23h	unkn.	2,600	20″	32,000,000	6,720,000	unkn.	6° 54′	♐ 13° 8′	♉ 14° 43′	34 1/10	1/27	unkn.	unkn.
Venus	224d 17h	24d 8h	7,906	30″	59,000,000	413,000	75° 0′	3° 20′	♒ 4° 20′	♊ 13° 59′	103 1/2	1	unkn.	unkn.
Earth	365d 6h	1d 0h	7,970	21″	82,000,000	1,377,000	23° 29′	0° 0′	♑ 8° 1′		104 1/2	1	1	100
Moon	365d 6h	29d 12 3/4h	2,180	6″	82,000,000	13,000	2° 10′	5° 18′		variable.	28 1/2	1/50	34/100	123 1/3
Mars	686d 23h	24h 40m	4,444	11″	125,000,000	11,439,000	0° 0′	1° 52′	♍ 0° 32′	♉ 17° 17′	58 1/2	1/5	unkn.	unkn.
Jupiter	4,332d 12h	9h 56m	81,000	37″	426,000,000	20,352,000	0° 0′	1° 20′	♎ 9° 10′	♋ 7° 29′	1,061 1/4	1,049	2	19
Saturn	10,759d 7h	unkn.	67,000	16″	780,000,000	42,735,000	unkn.	2° 30′	♐ 27° 50′	♋ 21° 13′	878 1/8	586	1 1/4	15

Sun and planets.	Proportion of light and heat.	Propor. quantity of matter.	Hourly motion in its orbit.	Hourly motion of its equator.	Square miles in surface.	Cubic miles in solidity.	Would fall to the sun in (days)	(h.)
Sun	45,000	227,500		3,818	1,828,911,000,000	232,577,115,137,000,000		
Mercury	6 1/2	unkn.	95,000	unkn.	21,236 [illegible]	9,195,534,500	15	13
Venus	1 1/2	unkn.	69,000	43	691 [illegible]51,300	258,507,832,200	39	17
Earth	1	1	58,000	1,042	19[illegible],852,860	265,404,598,080	64	10
Moon	1	1/36	2,290	9 1/3	14,898,750	5,408,246,000	64	10
Mars	3/7	unkn.	47,000	556	62,038,240	45,969,335,840	121	0
Jupiter	1/28	220	25,000	25,9[illegible]0	20,603,970,000	278,153,595,000,000	290	0
Saturn	1/80	94	18,000	unkn.	14,102,562,000	155,128,182,000,000	767	0

If the projectile force were destroyed.

Jupiter's Moons. N°.	Periods round Jupiter. D.	H.	M.
1	1	18	36
2	3	13	15
3	7	3	59
4	16	18	30

Saturn's Moons. N°.	Periods round Saturn. D.	H.	M.
1	1	21	19
[illegible]	2	17	40
3	4	12	25
4	15	22	41
5	79	7	48

If the Moon's projectile force were destroyed, she would fall to the Earth in 4 days 21 hours.

N. B. A larger and more accurate Table of this kind is given in the Supplement.

CHAP. III.

THE COPERNICAN SYSTEM DEMONSTRATED TO BE TRUE.

99. MATTER is of itself inactive, and indifferent to motion or rest. A body at rest can never put itself in motion; a body in motion can never stop or move slower of itself. Hence, when we see a body in motion, we conclude some other substance must have given it that motion; when we see a body fall from motion to rest, we conclude some other body or cause stopt it. Of matter and motion.

100. All motion is naturally rectilineal. A bullet thrown by the hand, or discharged from a cannon, would continue to move in the same direction it received at first, if no other power diverted it from its course. Therefore, when we see a body moving in a curve, of whatever kind, we conclude it must be acted upon by two powers at least: one to put it in motion, and another drawing it off from the rectilineal course in which it would otherwise have continued to move.

101. The power by which bodies fall towards the Earth, is called *gravity* or *attraction*. By this power in the Earth it is, that all bodies, on whatever side, fall in lines perpendicular to its surface. On opposite parts of the Earth, bodies fall in opposite directions, all towards the centre, where the whole force of gravity is as it were accumulated. By this power constantly acting on bodies near the Earth, they are kept from leaving it altogether; and those on its surface are kept thereto on all sides, so that they cannot fall from it. Bodies thrown with any obliquity are drawn by this power from a straight line into a curve, until they fall to the ground: the greater the force by which they are thrown, the greater is the distance they are carried before they fall. If we suppose a body carried several miles above the Earth, and there projected in an horizontal direction, with so great a velocity that it would move more than a semidiameter of the Earth, in the time it would take to fall to the Earth by gravity; in that case, if there were no resisting medium in the way, the body would not fall to the Earth at all, but continue to circulate round the Earth, keeping always the same path, and returning to the point from whence it was projected, with the same velocity as at first. Gravity demonstrable.

Projectile force demonstrable.

102. We find the Moon moves round the Earth in an orbit nearly circular. The Moon, therefore, must be acted on by two powers or forces; one of which would cause her to move in a right line, another bending her motion from that line into a curve. This attractive power must be seated in the Earth, for there is no other body within the Moon's orbit to draw her.[9] The attractive power of the Earth, therefore, extends to the Moon; and, in combination with her projectile force, causes her to move round the Earth in the same manner as the circulating body above supposed.

The Sun and planets attract each other.

103. The moons of Jupiter and Saturn are observed to move round their primary planets: therefore there is an attractive power in these planets. All the planets move round the Sun, and respect it for their centre of motion: therefore the Sun must be endowed with an attracting power, as well as the Earth and planets. The like may be proved of the comets. So that all the bodies or matter of the solar system are possessed of this power; and perhaps so is all matter whatsoever.[1]

104. As the Sun attracts the planets with their satellites, and the Earth the Moon, so the planets and satellites reattract the Sun, and the Moon the Earth; action and reaction being always equal. This is also confirmed by observation; for the Moon raises tides in the ocean, and the satellites and planets disturb one another's motions.

105. Every particle of matter being possessed of an attracting power, the effect of the whole must be in proportion to the

[9] If the Moon revolve in her orbit, in consequence of an attracting power residing in the Earth, she ought to be attracted as much from the tangent of her orbit in a minute, as heavy bodies fall at the Earth's surface in a second of time. Accordingly, it is found by calculation, that the Moon is deflected from the tangent, 16.[illegible] feet in a minute, which is the very space through which heavy bodies descend in a second of time at the Earth's surface.—*Ed.*

[1] The doctrine of universal gravitation has been completely proved by the deviation of the plumb lines of quadrants from the perpendicular, when placed in the vicinity of large and solid mountains. When the French astronomers, Bouguer and Condamine, were in Peru, they found that the large mountain Chimboraco, attracted the plumb line of the quadrant 8″ from its perpendicular position; and it appears from Dr. Maskelyne's experiments on *Shehallien* in Perthshire, that the deviation amounted in this case to 6″. See Phil. Trans. 1775, vol. lxv, p. 2. Mr. Cavendish suspended by a wire two leaden balls, fixed at the extremities of a wooden rod, and found that they were sensibly attracted, when two large masses of lead were placed at different distances from them.—*Ed.*

number of attracting particles: that is, to the quantity of matter in the body. This is demonstrated from experiments on pendulums: for, if they are of equal lengths, whatever their weights be, they always vibrate in equal times. Now, if one be double the weight of another, the force of gravity or attraction must be double, to make it oscillate with the same celerity: if one is thrice the weight or quantity of matter of another, it requires thrice the force of gravity to make it move with the same celerity. Hence it is certain, that the power of gravity is always proportional to the quantity of matter in bodies, whatever their bulks or figures are.

106. Gravity also, like all other virtues or emanations, either drawing or impelling a body towards a centre, decreases as the square of the distance increases: that is, a body at twice the distance attracts another with only a fourth part of the force; at four times the distance, with a sixteenth part of the force. This too is confirmed from observation, by comparing the distance which the Moon falls in a minute from a right line touching her orbit, with the space which bodies near the Earth fall in the same time (see § 102, note): and also by comparing the forces which retain Jupiter's moons in their orbits. This will be more fully explained in the seventh chapter.

107. The mutual attraction of bodies may be exemplified by a boat and a ship on the water, tied by a rope. Let a man, either in a ship or boat, pull the rope (it is the same in effect at which end he pulls, for the rope will be equally stretched throughout), the ship and boat will be drawn towards one another; but with this difference, that the boat will move as much faster than the ship, as the ship is heavier than the boat. Suppose the boat as heavy as the ship, and they will draw one another equally (setting aside the greater resistance of the water on the bigger body), and meet in the middle of the first distance between them. If the ship is 1,000 or 10,000 times heavier than the boat, the boat will be drawn 1,000 or 10,000 times faster than the ship; and meet proportionably nearer the place from which the ship set out. Now, whilst one man pulls the rope, endeavouring to bring the ship and boat together, let another man, in the boat, endeavour to row it off sideways, or at right angles to the rope; and the former, instead of being able to draw the boat to the ship, will find it enough for him to keep the boat from going

Gravitation and projection exemplified.

further off; whilst the latter, endeavouring to row off the boat in a straight line, will, by means of the other's pulling it towards the ship, row the boat round the ship at the rope's length from her. Here the power employed to draw the ship and boat to one another, represents the mutual attraction of the Sun and planets, by which the planets would fall freely towards the Sun with a quick motion; and would also in falling attract the Sun towards them. And the power employed to row off the boat, represents the projectile force impressed on the planets at right angles, or nearly so, to the Sun's attraction; by which means the planets move round the Sun, and are kept from falling to it. On the other hand, if it be attempted to make a heavy ship go round a light boat, they will meet sooner than the ship can get round; or the ship will drag the boat after it.

108. Let the above principles be applied to the Sun and Earth; and they will evince, beyond a possibility of doubt, that the Sun, not the Earth, is the centre of the system; and that the Earth moves round the Sun as the other planets do.

For, if the Sun moves about the Earth, the Earth's attractive power must draw the Sun towards it from the line of projection, so as to bend its motion into a curve. But the Sun being at least 227,000 times as heavy as the Earth, by being so much weightier, as its quantity of matter is greater, it must move 227,000 times as slowly toward the Earth, as the Earth does toward the Sun; and, consequently, the Earth would fall to the Sun in a short time, if it had not a very strong projectile motion to carry it off. The Earth, therefore, as well as every other planet in the system, must have a rectilineal impulse, to prevent its falling into the Sun. To say, that gravitation retains all the other planets in their orbits without affecting the Earth, which is placed between the orbits of Mars and Venus, is as absurd as to suppose that 6 cannon bullets might be projected upwards to different heights in the air, and that 5 of them should fall down to the ground; but the 6th, which is neither the highest nor the lowest, should remain suspended in the air without falling, and the Earth move round about it.

The absurdity of supposing the Earth at rest.

109. There is no such thing in nature as a heavy body moving round a light one as its centre of motion. A pebble fastened to a mill-stone by a string, may, by an easy impulse, be made to circulate round the mill-stone: but no impulse can make a

mill-stone circulate round a loose pebble, for the mill-stone would go off, and carry the pebble along with it.

110. The Sun is so immensely bigger and heavier than the Earth, (see chap. IX), that if he was moved out of his place, not only the Earth, but all the other planets, if they were united into one mass, would be carried along with the Sun, as the pebble would be with the mill-stone.

111. By considering the law of gravitation, which takes place throughout the solar system, in another light, it will be evident that the Earth moves round the Sun in a year, and not the Sun round the Earth. It has been shewn (§ 106) that the power of gravity decreases as the square of the distance increases; and from this it follows with mathematical certainty, that when two or more bodies move round another as their centre of motion, the squares of their periodic times will be to one another in the same proportion, as the cubes of their distances from the central body. This holds precisely with regard to the planets round the Sun, and the satellites round the planets; the relative distances of all which are well known. But, if we suppose the Sun to move round the Earth, and compare its period with the Moon's by the above rule, it will be found that the Sun would take no less than 173,510 days to move round the Earth, in which case our year would be 475 times as long as it now is. To this we may add, that the aspects of increase and decrease of the planets, the times of their seeming to stand still, and to move direct and retrograde, answer precisely to the Earth's motion; but not at all to the Sun, without introducing the most absurd and monstrous suppositions, which would destroy all harmony, order, and simplicity in the system. Moreover, if the Earth be supposed to stand still, and the stars to revolve in free spaces about the Earth in 24 hours, it is certain that the forces by which the stars revolve in their orbits are not directed to the Earth, but to the centres of the several orbits; that is, of the several parallel circles which the stars on different sides of the equator describe every day: and the like inferences may be drawn from the supposed diurnal motion of the planets, since they are never in the equinoctial but twice, in their courses with regard to the starry heavens. But, that forces should be directed to no central body, on which they physically depend, but to innumerable imaginary

The harmony of the celestial motions.

Kepler's law.

The absurdity of supposing the stars and planets to move round the Earth.

points in the axis of the Earth produced to the poles of the heavens, is an hypothesis too absurd to be entertained by any rational creature. And it is still more absurd to imagine, that these forces should increase exactly in proportion to the distances from this axis; for this is an indication of an increase to infinity; whereas the force of attraction is found to decrease in receding from the fountain from whence it flows. But the farther any star is from the quiescent pole, the greater must be the orbit which it describes; and yet it appears to go round in the same time as the nearest star to the pole does. And if we take into consideration the two-fold motion observed in the stars, one diurnal round the axis of the Earth in 24 hours, and the other round the axis of the ecliptic in 25,920 years, § 251, it would require an explication of such a perplexed composition of forces, as could by no means be reconciled with any physical theory.[2]

Objections against the Earth's motion answered.

112. There is but one objection of any weight that can be made against the Earth's motion round the Sun; which is, that in opposite points of the Earth's orbit, its axis, which always keeps a parallel direction, would point to different fixed stars, which is not found to be fact. But this objection is easily removed, by considering the immense distance of the stars in respect of the diameter of the Earth's orbit, the latter being no more than a point when compared to the former. If we lay a ruler on the side of a table, and along the edge of the ruler view the top of a spire at 10 miles distance, then lay the ruler on the opposite side of the table in a parallel situation to what it had before, and the spire will still appear along the edge of the ruler, because our eyes, even when assisted by the best instruments, are incapable of distinguishing so small a change at so great a distance.

113. Dr. Bradley, our present astronomer royal, has found by a long series of the most accurate observations, that there is a small apparent motion of the fixed stars, occasioned by the aberration of their light, and so exactly answering to an annual motion of the Earth, as evinces the same, even to a mathe-

[2] The striking difference between the light of the fixed stars and that of the planets, is a strong proof that the former shine by their own light, and have no connection with our system. The lustre of the star *Sirius* is much more brilliant than that of *Mercury* and *Venus*, which receive most light from the Sun; and yet Sirius is unquestionably situated without the orbit of the Georgium Sidus. There must always be a great difference between *reflected* or *borrowed* light, and that which is native or *direct*; as a considerable quantity of light is lost by reflection.—*Ed.*

matical demonstration. Those who are qualified to read the doctor's modest account of this great discovery, may consult the Philosophical Transactions, No. 406. Or they may find it treated of at large by Drs. Smith,[3] Long,[4] Desaguliers,[5] Rutherfurth, Mr. Maclaurin,[6] and M. de la Caille.[7]

114. It is true that the Sun seems to change his place daily, so as to make a tour round the starry heavens in a year. But whether the Sun or Earth moves, this appearance will be the same; for, when the Earth is in any part of the heavens, the Sun will appear in the opposite. And therefore, this appearance can be no objection against the motion of the Earth. **Why the Sun appears to change his place.**

115. It is well known to every person who has sailed on smooth water, or been carried by a stream in a calm, that however fast the vessel goes, he does not feel its progressive motion. The motion of the Earth is incomparably more smooth and uniform than that of a ship, or any machine made and moved by human art: and therefore it is not to be imagined that we can feel its motion.

116. We find that the Sun, and those planets on which there are visible spots, turn round their axes, for the spots move regularly over their discs.[8] From hence we may reasonably conclude, that the other planets, on which we see no spots, and the Earth, which is likewise a planet, have such rotations. But being incapable of leaving the Earth, and viewing it at a distance, and its rotation being smooth and uniform, we can neither see it move on its axis as we do the planets, nor feel ourselves affected by its motion. Yet there is one effect of such a motion, which will enable us to judge with certainty whether the Earth revolves on its axis or not. All globes which do not turn round their axis will be perfect spheres, on account of the equality of the weight of bodies on their surfaces; especially of the fluid parts. But all globes which turn on their axes will be oblate spheroids; that is, their surfaces will be higher, or farther from the centre, **The Earth's motion on its axis demonstrated.**

[3] Optics, b. 1, § 1178. [4] Astronomy, b. 2, § 838.

[5] Philosophy, vol. i, p. 401.

[6] Account of Newton's Philosoph. Discoveries, b. 3, c. 2, § 3.

[7] Elémens d'Astronomie, § 381.

[8] The face of the Sun, Moon, or any planet, as it appears to the eye, is called its

in the equatorial than in the polar regions; for, as the equatorial parts move quickest, they will recede farthest from the axis of motion, and enlarge the equatorial diameter. That our Earth is really of this figure, is demonstrable from the unequal vibrations of a pendulum, and the unequal lengths of degrees in different latitudes. Since then the Earth is higher at the equator than at the poles, the sea, which naturally runs downward, or towards the places which are nearest the centre, would run towards the polar regions, and leave the equatorial parts dry, if the centrifugal force of these parts, by which the waters were carried thither, did not keep them from returning. The Earth's equatorial diameter is 36 miles longer than its axis.*

All bodies heavier at the poles than they would be at the equator.

117. Bodies near the poles are heavier than those towards the equator, because they are nearer the Earth's centre, where the whole force of the Earth's attraction is accumulated. They are also heavier, because their centrifugal force is less, on account of their diurnal motion being slower For both these reasons, bodies carried from the poles towards the equator, gradually lose part of their weight. Experiments prove that a pendulum, which vibrates seconds near the poles, vibrates slower near the equator, which shews, that it is lighter, or less attracted there. To make it oscillate in the same time, it is found necessary to diminish its length By comparing the different lengths of pendulums swinging seconds at the equator and at London, it is found that a pendulum must be $2\frac{169}{1000}$ lines shorter at the equator than at the poles.[1] A line is the twelfth part of an inch.

How they might lose all their weight.

118. If the Earth turned round its axis in 84m 43s, the centrifugal force would be equal to the power of gravity at the equator; and all bodies there would entirely lose their weight. If the Earth revolved quicker, they would all fly off and leave it.

The Earth's motion cannot be felt.

119. A person on the Earth can no more be sensible of its undisturbed motion on its axis, than one in the cabin of a ship on smooth water can be sen-

* See § 76, note.

[1] By comparing the observations made at Paris and Spitzbergen, the length of a pendulum at the equator is 468.027 lines English, and the length of a pendulum at the pole 471.469 lines, so that a pendulum must be $2\frac{442}{1000}$ lines English shorter at the equator than at the poles.—*Ed.*

sible of the ship's motion when it turns gently and uniformly round. It is therefore no argument against the Earth's diurnal motion, that we do not feel it; nor is the apparent revolutions of the celestial bodies every day, a proof of the reality of these motions; for whether we or they revolve, the appearance is the very same. A person looking through the cabin windows of a ship as strongly fancies the objects on land to go round when the ship turns, as if they were actually in motion.

120. If we could translate ourselves from planet to planet, we should still find that the stars would appear of the same magnitudes, and at the same distances from each other, as they do to us here, because the width of the remotest planet's orbit bears no sensible proportion to the distance of the stars. But then, the heavens would seem to revolve about very different axes, and consequently, those quiescent points, which are our poles in the heavens, would seem to revolve about other points, which, though apparently in motion as seen from the Earth, would be at rest as seen from any other planet. Thus the axis of Venus, which lies almost at right angles to the axis of the Earth, would have its motionless poles in two opposite points of the heavens lying almost in our equinoctial, where the motion appears quickest, because it is seemingly performed in the greatest circle. And the very poles, which are at rest to us, have the quickest motion of all as seen from Venus. To Mars and Jupiter the heavens appear to turn round with very different velocities on the same axis, whose poles are about $23\frac{1}{2}°$ from ours. Were we on Jupiter, we should be at first amazed at the rapid motion of the heavens; the Sun and stars going round in 9^h 56^m. Could we go from thence to Venus, we should be as much surprised at the slowness of the heavenly motions; the Sun going but once round in 584^h, and the stars in 540^h. And could we go from Venus to the Moon, we should see the heavens turn round with a yet slower motion, the Sun in 708^h, the stars in 655^h. As it is impossible these various circumvolutions in such different times, and on such different axes, can be real, so it is unreasonable to suppose the heavens to revolve about our Earth more than it does about any other planet. When we reflect on the vast distance of the fixed stars, to which 190,000,000 of miles, the diameter of the Earth's orbit, is but a point, we are filled with amazement at the immensity

To the different planets the heavens appear to turn round on different axes.

of their distance. But if we try to frame an idea of the extreme rapidity with which the stars must move, if they move round the Earth in 24 hours, the thought becomes so much too big for our imagination, that we can no more conceive it than we do infinity or eternity. If the Sun was to go round the Earth in 24 hours, he must travel upwards of 300,000 miles in a minute; but the stars being at least 400,000 times as far from the Sun as the Sun is from us, those about the equator must move 400,000 times as quick. And all this to serve no other purpose than what can be as fully and much more simply obtained by the Earth's turning round eastward, as on an axis, every 24 hours, causing thereby an apparent diurnal motion of the Sun westward, and bringing about the alternate returns of day and night.

Objections against the Earth's diurnal motion answered.

121. As to the common objections against the Earth's motion on its axis, they are all easily answered and set aside. That it may turn without being seen or felt by us to do so, has been already shewn, § 119. But some are apt to imagine that, if the Earth turns eastward (as it certainly does, if it turns at all), a ball fired perpendicularly upward in the air must fall considerably westward of the place it was projected from. The objection, which at first seems to have some weight, will be found to have none at all, when we consider that the gun and ball partake of the Earth's motion; and therefore the ball being carried forward with the air as quick as the earth and air turn, must fall down on the same place. A stone let fall from the top of a main-mast, if it meets with no obstacle, falls on the deck as near the foot of the mast when the ship sails as when it does not. If an inverted bottle, full of liquor, be hung up to the ceiling of the cabin, and a small hole be made in the cork to let the liquor drop through on the floor, the drops will fall just as far forward on the floor when the ship sails as when it is at rest. And gnats or flies can as easily dance among one another in a moving cabin as in a fixed chamber. As for those scripture expressions which seem to contradict the Earth's motion, this general answer may be made to them all, viz. it is plain from many instances, that the scriptures were never intended to instruct us in philosophy or astronomy; and therefore, on those subjects, expressions are not always to be taken in the literal sense, but for the most part as accommodated to

the common apprehensions of mankind. Men of sense in all ages, when not treating of the sciences purposely, have followed this method; and it would be in vain to follow any other in addressing ourselves to the vulgar, or bulk of any community. Moses calls the Moon a great luminary (as it is in the Hebrew) as well as the Sun: but the Moon is known to be an opaque body, and the smallest that astronomers have observed in the heavens, and shines upon us not by any inherent light of its own, but by reflecting the light of the Sun. If Moses had known this, and told the Israelites so, they would have stared at him; and considered him rather as a madman, than as a person commissioned by the Almighty to be their leader.

CHAP. IV.

THE PHENOMENA OF THE HEAVENS AS SEEN FROM DIFFERENT PARTS OF THE EARTH.

122. We are kept to the Earth's surface on all sides by the power of its central attraction, which, laying hold of all bodies according to their densities or quantities of matter, without regard to their bulks, constitutes what we call their weight. And having the sky over our heads, go where we will, and our feet towards the centre of the Earth, we call it up over our heads, and down under our feet; although the same right line which is down to us, if continued through and beyond the opposite side of the Earth, would be up to the inhabitants on the opposite side. For, the inhabitants *n*, *i*, *e*, *m*, *s*, *o*, *q*, *l*, stand with their feet toward the Earth's centre *C*; and have the same figure of sky *N*, *I*, *E*, *M*, *S*, *O*, *Q*, *L*, over their heads. Therefore, the point *S* is as directly upward to the inhabitant *s* on the south pole, as *N* is to the inhabitant *n* on the north pole; so is *E* to the inhabitant *e* supposed to be on the north end of Peru; and *Q* to the opposite inhabitant *q* on the middle of the island Sumatra. Each of these observers is surprised that his opposite or antipode can stand with his head hanging downwards. But let either go to the other, and he will tell him that he stood as upright and firm on the place where he was, as he now stands where he is. To all these

We are kept to the Earth by gravity.

Plate II, Fig. 1.

Antipodes.

observers the Sun, Moon, and stars seem to turn round the points *N* and *S*, as the poles of the fixed axis *NCS*, because the Earth does really turn round the mathematical line *nCs* as round an axis, of which *n* is the north pole, and *s* the south pole. The inhabitant *U* affirms, that he is on the uppermost side of the Earth, and wonders how another at *L* can stand on the undermost side with his head hanging downwards. But *U* in the meantime forgets that in 12 hours time he will be carried half round with the Earth, and then be in the very situation that *L* now is, although as far from him as before. And yet, when *U* comes there, he will find no difference as to his manner of standing; only he will see the opposite half of the heavens, and imagine the heavens to have gone half round the Earth.

Axis of the world.
Its poles.
Fig. 2.

How our Earth might have an upper and an under side.

123. When we see a globe hung up in a room, we cannot help imagining it to have an upper and an under side, and immediately form a like idea of the Earth; from whence we conclude, that it is as impossible for people to stand on the under side of the Earth, as for pebbles to lie on the under side of a common globe, which instantly fall down from it to the ground; and well they may, because the attraction of the Earth being greater than the attraction of the globe, pulls them away. Just so would be the case with our Earth, if it were placed near a globe much bigger than itself, such as Jupiter, for then it would really have an upper and an under side with respect to that large globe, which, by its attraction, would pull away every thing from the side of the Earth next to it, and only those on the top of the opposite or upper side could remain upon it. But there is no larger globe near enough our Earth to overcome its central attraction, and therefore it has no such thing as an upper and an under side; for all bodies on or near its surface, even to the Moon, gravitate towards its centre.

124. Let any man imagine that the Earth and every thing but himself is taken away, and he left alone in the midst of indefinite space; he could then have no idea of up or down; and were his pockets full of gold, he might take the pieces one by one, and throw them away on all sides of him, without any danger of losing them; for the attraction of his body would bring them all back by the ways they went, and he would be

down to every one of them. But then, if a sun or any other large body were created, and placed in any part of space several millions of miles from him, he would be attracted towards it, and could not save himself from falling down to it.

125. The Earth's bulk is but a point, as that at C compared to the heavens; and therefore every inhabitant upon it, let him be where he will, as at *n*, *e*, *m*, *s*, &c. sees half of the heavens. The inhabitant *n* on the north pole of the Earth, constantly sees the hemisphere *ENQ*; and having the north pole *N* of the heavens just over his head, his horizon[1] coincides with the celestial equator *ECQ*. Therefore all the stars in the northern hemisphere *ENQ*, between the equator and north pole, appear to turn round the line *NC*, moving parallel to the horizon. The equatorial stars keep in the horizon, and all those in the southern hemisphere *ESQ* are invisible. The like phenomena are seen by the observer *s* on the south pole, with respect to the hemisphere *ESQ*, and to him the opposite hemisphere is always invisible. Hence, under either pole, only one-half of the heavens is seen; for those parts which are once visible never set, and those which are once invisible never rise. But the ecliptic *YCX*, or orbit which the Sun appears to describe once a-year by the Earth's annual motion, has the half *YC* constantly above the horizon *ECQ* of the north pole *n*, and the other half *CX* always below it. Therefore, whilst the Sun describes the northern half *YC* of the ecliptic, he neither sets to the north pole nor rises to the south; and whilst he describes the southern half *CX*, he neither sets to the south pole, nor rises to the north. The same things are true with respect to the Moon, only with this difference, that as the Sun describes the ecliptic but once a-year, he is for half that time visible to each pole in its turn, and as long invisible; but as the Moon goes round the ecliptic in 27^{d} 8^{h}, she is only visible for 13^{d} 16^{h}, and as long invisible to each pole by turns. All the planets likewise rise and set to the poles, because their orbits are cut obliquely in halves by the horizon of the poles. When the Sun (in his apparent way from *X*) arrives at *C*, which is on the 20th of March, he is just rising to an observer at *n* on the north pole, and setting to another at *s* on the south

Plate II. Fig. 1.

Half of the heavens visible to an inhabitant on any part of the Earth.

Phenomena at the poles.

[1] The utmost limit of a person's view, where the sky seems to touch the Earth all around, is called his *Horizon*, which shifts as the person changes his place.

pole. From *C* he rises higher and higher in every apparent diurnal revolution, till he comes to the highest point of the ecliptic *y*, on the 21st of June, and then he is at his greatest altitude, which is 23½°, or the arc *Ey*, equal to his greatest north declination; and from thence he seems to descend gradually in every apparent circumvolution, till he sets at *C* on the 23d of September, and then he goes to exhibit the like appearances at the south pole for the other half of the year. Hence, the Sun's apparent motion round the Earth is not in parallel circles, but in spirals, such as might be represented by a thread wound round a globe from tropic to tropic, the spirals being at some distance from one another about the equator, and gradually nearer to each other as they approach toward the tropics.

Phenomena at the equator.

Fig. 1.

126. If the observer be anywhere on the terrestrial equator *eCq*, as suppose at *e*, he is in the plane of the celestial equator, or under the equinoctial *ECQ*; and the axis of the Earth *nCs* is coincident with the plane of his horizon, extended out to *N* and *S*, the north and south poles of the heavens. As the Earth turns round the line *NCS*, the whole heavens *MOLI* seem to turn round the same line, but the contrary way. It is plain that this observer has the celestial poles constantly in his horizon, and that his horizon cuts the diurnal paths of all the celestial bodies perpendicularly and in halves. Therefore the Sun, planets, and stars rise every day, and ascend perpendicularly above the horizon for 6 hours, and passing over the meridian, descend in the same manner for the six hours following; then set in the horizon, and continue 12 hours below it. Consequently, at the equator the days and nights are equally long throughout the year. When the observer is in the situation *e*, he sees the hemisphere *SEN*, but in 12 hours after he is carried half round the Earth's axis to *q*, and then the hemisphere *SQN* becomes visible to him, and *SEN* disappears. Thus we find that to an observer at either of the poles one-half of the sky is always visible, and the other half never seen; but to an observer on the equator, the whole sky is seen every 24 hours.

The figure here referred to represents a celestial globe of glass, having a terrestrial globe within it, after the manner of the glass sphere invented by my generous friend Dr. Long, professor of astronomy in Cambridge.

127. If a globe be held sidewise to the eye at some distance, and so that neither of its poles can be seen, the equator ECQ, and all circles parallel to it, as DL, yxx, abX, MO, &c. will appear to be straight lines, as projected in this figure, which is requisite to be mentioned here, because we shall have occasion to call them circles in the following articles of this chapter.[a] — Remark.

128. Let us now suppose that the observer has gone from the equator e towards the north pole n, and that he stops at i, from which place he then sees the hemisphere $MEINL$, his horizon MCL having shifted as many degrees from the celestial poles N and S, as he has travelled from under the equinoctial E. And as the heavens seem constantly to turn round the line NCS as an axis, all those stars which are not so many degrees from the north pole N as the observer is from the equinoctial, namely, the stars north of the parallel DL, never set below the horizon; and those which are south of the parallel MO never rise above it. Hence the former of these two parallel circles is called the circle of perpetual apparition, and the latter the circle of perpetual occultation, but all the stars between these two circles rise and set every day. Let us imagine many circles to be drawn between these two, and parallel to them; those which are on the north side of the equinoctial will be unequally cut by the horizon MCL, having larger portions above the horizon than below it, and the more so, as they are nearer to the circle of perpetual apparition; but the reverse happens to those on the south side of the equinoctial, whilst the equinoctial is divided in two equal parts by the horizon. Hence, by the apparent turning of the heavens, the northern stars describe greater arcs or portions of circles above the horizon than below it; and the greater, as they are farther from the equinoctial towards the circle of perpetual apparition, whilst the contrary happens to all stars south of the equinoctial; but those upon it describe equal arcs both above and below the horizon, and therefore they are just as long above as below it. — Phenomena between the equator and poles. — The circles of perpetual apparition and occultation.

129. An observer on the equator has no circle of perpetual

[a] A circle, or a thin circular plate, being turned edgewise to the eye, so that none of its plane surfaces are seen, appears to be a straight line; and when one of these surfaces is seen, it appears to be an ellipse approaching nearer and nearer to a circle as the eye rises above the circular plane, or as its inclination diminishes.

apparition or occultation, because all the stars, together with the Sun and Moon, rise and set to him every day. But, as a bare view of the figure is sufficient to shew that these two circles *DL* and *MO* are just as far from the poles *N* and *S* as the observer at *i* (or one opposite to him at *o*) is from the equator *ECQ*; it is plain, that if an observer begins to travel from the equator towards either pole, his circle of perpetual apparition rises from that pole as from a point, and his circle of perpetual occultation from the other. As the observer advances towards the nearer pole, these two circles enlarge their diameters, and come nearer one another, until he comes to the pole, and then they meet and coincide in the equinoctial. On different sides of the equator, to observers at equal distances from it, the circle of perpetual apparition to one is the circle of perpetual occultation to the other.

Why the stars always describe the same parallel of motion, and the Sun a different.

130. Because the stars never vary their distances from the equinoctial, so as to be sensible in an age, the lengths of their diurnal and nocturnal arcs are always the same to the same places on the Earth. But as the Earth goes round the Sun every year in the ecliptic, one-half of which is on the north side of the equinoctial, and the other half on its south side, the Sun appears to change his place every day, so as to go once round the circle *YCX* every year, § 114. Therefore, whilst the Sun appears to advance northward, from having described the parallel *a b X* touching the ecliptic in *X*, the days continually lengthen and the nights shorten, until he comes to *Y*, and describes the parallel *y z x*, when the days are at the longest and the nights at the shortest; for then, as the Sun goes no farther northward, the greatest portion that is possible of the diurnal arc *yz* is above the horizon of the inhabitant *i*, and the smallest portion *zx* below it. As the sun declines southward from *y*, he describes smaller diurnal and greater nocturnal arcs, or portions of circles every day, which causeth the days to shorten and nights to lengthen, until he arrives again at the parallel *a b X*; which having only the small part *a b* above the horizon *MCL*, and the great part *b X* below it, the days are at the shortest, and the nights at the longest, because the Sun recedes no farther south, but returns northward as before. It is easy to see that the Sun must be in the equinoctial *ECQ* twice every year, and then the days and nights are equally

long, that is 12 hours each. These hints serve at present to give an idea of some of the appearances resulting from the motions of the Earth, which will be more particularly described in the 10th chapter.

131. To an observer at either pole, the horizon and equinoctial are coincident, and the Sun and stars seem to move parallel to the horizon; therefore such an observer is said to have a parallel position of the sphere. To an observer anywhere between either pole and equator, the parallels described by the Sun and stars are cut obliquely by the horizon, and therefore he is said to have an oblique position of the sphere. To an observer anywhere on the equator, the parallels of motion described by the Sun and stars, are cut perpendicularly, or at right angles, by the horizon, and therefore he is said to have a right position of the sphere. And these three are all the different ways that the sphere can be posited to all people on the earth. Fig. 1. Parallel, oblique, and right sphere, what.

CHAP. V

THE PHENOMENA OF THE HEAVENS AS SEEN FROM DIFFERENT PARTS OF THE SOLAR SYSTEM.

132. So vastly great is the distance of the starry heavens, that if viewed from any part of the solar system, or even many millions of miles beyond it, the appearance would be the very same to us. The Sun and stars would all seem to be fixed on one concave surface, of which the spectator's eye would be the centre. But the planets being much nearer than the stars, their appearances will vary considerably with the place from which they are viewed.

133. If the spectator is at rest without their orbits, the planets will seem to be at the same distance as the stars, but continually changing their places with respect to the stars, and to one another; assuming various phases of increase and decrease like the Moon. And notwithstanding their regular motions about the Sun, will sometimes appear to move quicker, sometimes slower, be as often to the west as to the east of the Sun, and at their greatest distances seem quite stationary. The duration, extent, and distance of those points in

where these digressions begin and end, would be more or less, according to the respective distances of the several planets from the Sun; but in the same planet they would continue invariably the same at all times, like pendulums of unequal lengths oscillating together, the shorter move quick and go over a small space, the longer move slow and go over a large space. If the observer is at rest within the orbits of the planets, but not near the common centre, their apparent motions will be irregular, but less so than in the former case. Each of the several planets will appear bigger and less by turns as they approach nearer to or recede farther from the observer, the nearest varying most in their size. They will also move quicker or slower with regard to the fixed stars, but will never be retrograde or stationary.

134. If an observer in motion views the heavens, the same apparent irregularities will be observed, but with some variation resulting from his own motion. If he is on a planet which has a rotation on its axis, not being sensible of his own motion, he will imagine the whole heavens, Sun, planets, and stars, to revolve about him in the same time that his planet turns round, but the contrary way, and will not be easily convinced of the deception. If his planet moves round the Sun, the same irregularities and aspects as above mentioned will appear in the motions of the other planets; and the Sun will seem to move among the fixed stars or signs, directly opposite to those in which his planet moves, changing its place every day as he does. In a word, whether our observer be in motion or at rest, whether within or without the orbits of the planets, their motions will seem irregular, intricate, and perplexed, unless he is in the centre of the system, and from thence the most beautiful order and harmony will be seen.

The sun's centre the only point from which the true motions and places of the planets could be seen.

135. The Sun being the centre of all the planets' motions, the only place from which their motions could be truly seen, is the Sun's centre, where the observer being supposed not to turn round with the Sun (which, in this case, we must imagine to be a transparent body), would see all the stars at rest, and seemingly equidistant from him. To such an observer, the planets would appear to move among the fixed stars, in a simple, regular, and uniform manner; only, that as in equal times they describe equal areas, they would describe

spaces somewhat unequal, because they move in elliptic orbits, § 155. Their motions would also appear to be what they are in fact, the same way round the heavens, in paths which cross at small angles in different parts of the heavens, and then separate a little from one another, § 20. So that, if the solar astronomer should make the path or orbit of any planet a standard, and consider it as having no obliquity, § 201, he would judge the paths of all the rest to be inclined to it, each planet having one-half of its path on one side, and the other half on the opposite side of the standard path or orbit. And if he should ever see all the planets start from a conjunction with each other,[3] Mercury would move so much faster than Venus as to overtake her again, (though not in the same point of the heavens) in a quantity of time almost equal to 145 of our days and nights, or, as we commonly call them, natural days, which include both the days and nights. Venus would move so much faster than the Earth, as to overtake it again in 585 natural days. The Earth so much faster than Mars, as to overtake him again in 778 such days. Mars so much faster than Jupiter, as to overtake him again in 817 such days; and Jupiter so much faster than Saturn, as to overtake him again in 7236 days, all of our time.

136. But as our solar astronomer could have no idea of measuring the courses of the planets by our days, he would probably take the period of Mercury, which is the quickest moving planet, for a measure to compare the periods of the others by. As all the stars would appear quiescent to him, he would never think that they had any dependence upon the Sun; but would naturally imagine that the planets have, because they move round the Sun. And it is by no means improbable, that he would conclude those planets, whose periods are quickest, to move in orbits proportionably less than those do which make slower circuits. But being destitute of a method for finding their parallaxes, or, more properly speaking, as they could have no parallax to him, he could never know any thing of their real distances or magnitudes. Their

The judgment that a solar astronomer would probably make concerning the distances and bulks of the planets.

[3] Here we do not mean such a conjunction, as that the nearer planet should hide all the rest from the observer's sight; (for that would be impossible, unless the intersections of all their orbits were coincident, which they are not: see § 21,) but when they were all in a line crossing the standard orbit at right angles.

relative distances he might perhaps guess at by their periods, and from thence infer something of truth concerning their relative bulks, by comparing their apparent bulks with one another. For example, Jupiter appearing bigger to him than Mars, he would conclude it to be much bigger in fact; because it appears so, and must be farther from him, on account of its longer period. Mercury and the Earth would seem much of the same bulk, but by comparing its period with the Earth's, he would conclude that the Earth is much farther from him than Mercury, and, consequently, that it must be really bigger, though apparently of the same bulk; and so of the rest. And as each planet would appear somewhat bigger in one part of its orbit than in the opposite, and to move quickest when it seems biggest, the observer would be at no loss to conclude that all the planets move in orbits, of which the Sun is not precisely in the centre.

The planetary motions very irregular as seen from the earth.

137. The apparent magnitudes of the planets continually change as seen from the Earth, which demonstrates that they approach nearer to it, and recede farther from it by turns. From these phenomena, and their apparent motions among the stars, they seem to describe looped curves, which never return into themselves, Venus's path excepted. And if we were to trace out all their apparent paths, and put the figures of them together in one diagram, they would appear so anomalous and confused, that no man in his senses could believe them to be representations of their real paths; but would immediately conclude, that such apparent irregularities must be owing to some optic illusions. And, after a good deal of inquiry, he might perhaps be at a loss to find out the true cause of these irregularities; especially if he were one of those who would rather, with the greatest justice, charge frail man with ignorance, than the Almighty with being the author of such confusion.

Those of Mercury and Venus represented.

138. Dr. Long, in his first volume of Astronomy, has given us figures of the apparent paths of all the planets, separately from Cassini; and on seeing them I first thought of attempting to trace some of them by a machine (the *Orrery*, at the beginning of the Plates) that shews the motions of the Sun, Mercury, Venus, the Earth, and Moon, according to the Copernican system. Having taken off the Sun, Mercury, and Venus, I put black lead pencils in their

places, with the points turned upward; and fixed a circular sheet of paste-board so, that the Earth kept constantly under its centre in going round the Sun; and the paste-board kept its parallelism. Then pressing gently with one hand upon the paste-board, to make it touch the three pencils, with the other hand I turned the winch that moves the whole machinery: and as the Earth, together with the pencils in the places of Mercury and Venus, had their proper motions round the Sun's pencil, which kept at rest in the centre of the machine, all the three pencils described a diagram, from which the first figure of the third plate is truly copied in a smaller size. As the Earth moved round the Sun, the Sun's pencil described the dotted circle of months, whilst Mercury's pencil drew the curve with the greatest number of loops, and Venus's that with the fewest. In their inferior conjunctions they come as much nearer the Earth, or within the circle of the Sun's apparent motion round the heavens, as they go beyond it in their superior conjunctions. On each side of the loops they appear stationary; in that part of each loop next the Earth retrograde; and in all the rest of their paths direct.

Plate III. Fig. 1.

If Cassini's figures of the paths of the Sun, Mercury, and Venus, were put together, the figure as above traced out, would be exactly like them. It represents the Sun's apparent motion round the ecliptic, which is the same every year; Mercury's motion for seven years, and Venus's for eight; in which time Mercury's path makes 23 loops, crossing itself so many times, and Venus's only 5. In 8 years Venus falls so nearly into the same apparent path again, as to deviate very little from it in some ages; but in what number of years Mercury and the rest of the planets would describe the same visible paths over again, I cannot at present determine. Having finished the above figure of the paths of Mercury and Venus, I put the ecliptic round them as in the Doctor's book; and added the dotted lines from the Earth to the ecliptic for shewing Mercury's apparent or geocentric motion therein for one year; in which time his path makes three loops, and goes on a little farther, which shews that he has three inferior, and as many superior, conjunctions with the Sun in that time; and also that he is six times stationary, and thrice retrograde. Let us now trace his motion for one year in the figure.

Suppose Mercury to be setting out from *A* towards *B*

Fig. 1. (between the earth and left hand corner of the plate), and as seen from the earth, his motion will then be direct, or according to the order of the signs. But when he comes to *B*, he appears to stand still in the 21° of ♐ at *F*, as shewn by the line *B F*. Whilst he goes from *B* to *C*, the line *B F*, supposed to move with him, goes backward from *F* to *E*, or contrary to the order of signs; and when he is at *C*, he appears stationary at *E*, having gone back 11½°. Now, suppose him stationary on the 1st of January at *C*, on the 10th thereof he will appear in the heavens as at 20, near *E*; on the 20th he will be seen as at *G*; on the 31st at *H*; on the 10th of February at *I*; on the 20th at *K*; and on the 28th at *L*; as the dotted lines shew, which are drawn through every 10th day's motion in his looped path, and continued to the ecliptic. On the 10th of March he appears at *M*; on the 20th at *N*; and on the 31st at *O*. On the 10th of April he appears stationary at *P*; on the 20th he seems to have gone back again to *O*, and on the 30th he appears stationary at *Q*, having gone back 11½°. Thus Mercury seems to go forward 4s 11°, or 131°; and to go back only 11° or 12°, at a mean rate. From the 30th of April to the 10th of May, he seems to move from *Q* to *R*; and on the 20th he is seen at *S*, going forward in the same manner again, according to the order of letters, and backward when they go back; which it is needless to explain any farther, as the reader can trace him out so easily, through the rest of the year. The same appearances happen in Venus's motion; but as she moves slower than Mercury, there are longer intervals of time between them.

Having already, § 120, given some account of the apparent diurnal motions of the heavens as seen from the different planets, we shall not trouble the reader any more with that subject.

CHAP. VI.

THE PTOLEMEAN SYSTEM REFUTED.—THE MOTIONS AND PHASES OF MERCURY AND VENUS EXPLAINED.

169. The Tychonic system, § 97, being sufficiently refuted by the 109th article, we shall say nothing more about it.

140. The Ptolemean system, § 96, which asserts the Earth to be at rest in the centre of the universe, and all the planets with the Sun and stars to move round it, is evidently false and absurd; for, if this hypothesis were true, Mercury and Venus could never be hid behind the Sun, as their orbits are included within the Sun's: and, again, these two planets would always move direct, and be as often in opposition to the Sun as in conjunction with him. But the contrary of all this is true: for they are just as often behind the Sun as before him, appear as often to move backwards as forwards, and are so far from being seen at any time in the side of the heavens opposite to the Sun, that they were never seen a quarter of a circle in the heavens distant from him.

141. These two planets, when viewed at different times with a good telescope, appear in all the various shapes of the moon; which is a plain proof that they are enlightened by the Sun, and shine not by any light of their own: for if they did, they would constantly appear round as the Sun does; and could never be seen like dark spots upon the Sun when they pass directly between him and us. Their regular phases demonstrate them to be spherical bodies; as may be shown by the following experiment.

Appearances of Mercury and Venus.

Hang an ivory ball by a thread, and let any person move it round the flame of a candle, at two or three yards distance from your eye; when the ball is beyond the candle, so as to be almost hid by the flame, its enlightened side will be towards you, and appear round like the full moon: when the ball is between you and the candle, its enlightened side will disappear, as the Moon does at the change: when it is half-way between these two positions, it will appear half illuminated, like the Moon in her quarters; but in every other place between these positions, it will appear more or less horned, or gibbous. If this experiment be made with a flat circular plate, you may make it appear fully enlightened, or not enlightened at all; but can never make it seem either horned or gibbous.

Experiment to prove they are round.

142. If you remove about six or seven yards from the candle, and place yourself so that its flame may be just about the height of your eye, and then desire the other person to move the ball slowly round the candle as before, keeping it as near of an equal

Experiment to represent the motions of Mercury and Venus.

height with the flame as he possibly can, the ball will appear to you not to move in a circle, but to vibrate backward and forward like a pendulum, moving quickest when it is directly between you and the candle, and when directly beyond it; and gradually slower as it goes farther to the right or left side of the flame, until it appears at the greatest distance from the flame; and then, though it continues to move with the same velocity, it will seem to stand still for a moment. In every revolution it will shew all the above phases, § 141; and if two balls, a smaller and a greater, be moved in this manner round the candle, the smaller ball being kept nearest the flame, and carried round almost three times as often as the greater, you will have a tolerable good representation of the apparent motions of Mercury and Venus; especially, if the bigger ball describes a circle almost twice as large in diameter as the circle described by the lesser.

Plate II. Fig. 3. 143. Let *A B C D E* be a part or segment of the visible heavens, in which the Sun, Moon, planets, and stars, appear to move at the same distance from the Earth *E*. For there are certain limits beyond which the eye cannot judge of different distances; as is plain from the Moon's appearing to be as far from us as the Sun and Stars are. Let the circle *f g h i k l m n o* be the orbit in which Mercury *m* moves round the Sun *S*, according to the order of the letters. When Mercury is at *f*, he disappears to the Earth at *E*, because his enlightened side is turned from it; unless he be then in one of his nodes, § 20, 25; in which case he will appear like a dark spot upon the Sun. When he is at *g* in his orbit, he appears at *B* in the Heavens, Westward of the Sun *S*, which is at *C*: when at *h* he appears at *A*, at his greatest western elongation or distance from the Sun; and then seems to stand still. But, as he moves from *h* to *i*, he appears to go from *A* to *B*; and seems to be in the same place when at *i*, as when he was at *g*, but not near so big: at *k* he is hid from the earth *E* by the Sun *S*; being then in his superior conjunction. In going from *k* to *l*, he appears to move from *C* to *D*; and when he is at *n* he appears stationary at *E*; being seen as far East from the Sun then, as he was West from him at *A*. In going from *n* to *o* in his orbit, he seems to go back again in the Heavens, from *E* to *D*; and is seen in the same place (with respect to the Sun) at *o*, as when

The elongations or digressions of Mercury from the Sun.

he was at *l*; but of a larger diameter at *o*, because he is then nearer the Earth *E*: and when he comes to *f*, he again passes by the Sun, and disappears as before. In going from *n* to *h* in his orbit, he seems to go backward in the Heavens from *E* to *A*; and in going from *h* to *n*, he seems to go forward from *A* to *E*. As he goes on from *f*, a little of his enlightened side at *g* is seen from *E*; at *h* he appears half full, because half of his enlightened side is seen; at *i*, gibbous, or more than half full; and at *k* he would appear quite full, were he not hid from the Earth *E* by the sun *S*. At *l* he appears gibbous again: at *n* half decreased, at *o*, horned, and at *f* new, like the Moon at her change. He goes sooner from his eastern station at *n*, to his western station at *h*, than from *h* to *n* again; because he goes through less than half his orbit in the former case, and more in the latter.

144. In the same figure, let *F G H I K L M N* be the orbit in which Venus *v* goes round the Sun *S*, according to the order of the letters: and let *E* be the Earth, as before. When Venus is at *F*, she is in her inferior conjunction; and disappears, like the new Moon, because her dark side is toward the Earth. At *G*, she appears half enlightened to the Earth, like the Moon in her first quarter: at *H* she appears gibbous; at *I* almost full, her enlightened side being then nearly towards the Earth; at *K* she would appear quite full to the Earth *E*; but is hid from it by the Sun *S*: at *L* she appears upon the decrease, or gibbous; at *M* more so; at *N* only half enlightened; and at *F* she disappears again. In moving from *N* to *G*, she seems to go backward in the heavens; and from *G* to *N*, forwards; but as she describes a much greater portion of her orbit in going from *G* to *N*, than from *N* to *G*, she appears much longer direct than retrograde in her motion. At *N* and *G*, she appears stationary, as Mercury does at *n* and *h*. Mercury, when stationary, seems to be only 28° from the Sun; and Venus, when so, 47°; which is a demonstration that Mercury's orbit is included within Venus's, and Venus's within the Earth's.

Plate II. Fig. 3.

The elongations and phases of Venus.

The greatest elongations of Mercury and Venus.

145. Venus, from her superior conjunction at *K* to her inferior conjunction at *F*, is seen on the East side of the Sun *S* to the Earth *E*; and therefore she shines in the evening, after the Sun sets, and is called the evening star: for, the Sun being

Morning and evening Star, what.

then to the westward of Venus, he must set first. From her inferior conjunction to her superior, she appears on the west side of the Sun; and therefore rises before him, for which reason she is called the morning star. When she is about N or G, she shines so bright, that bodies cast shadows in the night-time.[4]

The stationary places of the planets variable.

146. If the Earth kept always at E, it is evident that the stationary places of Mercury and Venus would always be in the same points of the heavens where they were before. For example: whilst Mercury m goes from h to n, according to the order of the letters, he appears to describe the arc $A\,B\,C\,D\,E$ in the heavens direct; and whilst he goes from n to h, he seems to describe the same arc back again, from E to A, retrograde: always at n and h he appears stationary at the same points E and A, as before. But Mercury goes round his orbit from f to f again, in 88 days; and yet there are 116 days from any one of his conjunctions, or apparent stations, to the same again: and the places of these conjuctions and stations are found to be about 114° eastward from the points of the heavens where they were last before; which proves that the Earth has not kept all that time at E, but has had a progressive motion in its orbit from E to t. Venus also differs every time in the places of her conjunctions and stations; but much more than Mercury; because as Venus describes a much larger orbit than Mercury does, the Earth advances so much the farther in its annual path before Venus comes round again.

The elongations of all Saturn's inferior planets as seen from him.

147. As Mercury and Venus, seen from the Earth, have their respective elongations from the Sun, and stationary places; so has the Earth, seen from Mars; and Mars, seen from Jupiter; and Jupiter, seen from Saturn: that is, to every superior planet, all the inferior ones have their stations and elongations; as Venus and Mercury have to the Earth. As seen from Saturn, Mercury never goes more than $2\frac{1}{2}$° from the Sun; Venus $4\frac{1}{3}$; the Earth 6; Mars $9\frac{1}{2}$; and Jupiter $33\frac{1}{2}$; so that Mercury, as seen from the Earth, has almost as great a digression or elongation from the Sun, as Jupiter seen from Saturn.

[4] The planet Venus is brightest 36 days before and after her inferior conjunction with the Sun, her elongation being then 39° 44′.

148. Because the Earth's orbit is included within the orbits of Mars, Jupiter, and Saturn, they are seen on all sides of the heavens: and are as often in opposition to the Sun as in conjunction with him. If the Earth stood still, they would always appear direct in their motions; never retrograde nor stationary. But they seem to go just as often backward as forward; which, if gravity be allowed to exist, affords a sufficient proof of the Earth's annual motion: and without its existence, the planets could never fall from the tangents of their orbits towards the Sun, nor could a stone, which is once thrown up from the Earth, ever fall to the Earth again.

A proof of the Earth's annual motion.

149. As Venus and the Earth are superior planets to Mercury, they shew much the same appearances to him that Mars and Jupiter do to us. Let Mercury *m* be at *f*, Venus *v* at *F*, and the Earth at *E*; in which situation Venus hides the Earth from Mercury; but, being in opposition to the Sun, she shines on Mercury with a full illumined orb; though, with respect to the Earth, she is in conjunction with the Sun, and invisible. When Mercury is at *f*, and Venus at *G*, her enlightened side not being directly towards him, she appears a little gibbous, as Mars does in a like situation to us: but, when Venus is at *I*, her enlightened side is so much toward Mercury at *f*, that she appears to him almost of a round figure. At *K*, Venus disappears to Mercury at *f*, being then hid by the Sun; as well as all our superior planets are to us, when in conjunction with the Sun. When Venus has, as it were, emerged out of the Sun-beams, as at *L*, she appears almost full to Mercury at *f*; at *M* and *N*, a little gibbous; quite full at *F*, and largest of all; being then in opposition to the Sun, and consequently nearest to Mercury at *F*; shining strongly on him in the night, because her distance from him then is somewhat less than a fifth part of her distance from the Earth, when she appears roundest to it between *I* and *K*, or between *K* and *L*, as seen from the Earth *E*. Consequently, when Venus is opposite to the Sun, as seen from Mercury, she appears more than 25 times as large to him as she does to us when at the fullest. Our case is almost similar with respect to Mars, when he is opposite to the Sun; because he is then so near the Earth, and has his whole enlightened side towards it. But, because

Plate II. Fig. 3. General phenomena of a superior planet to an inferior.

the orbits of Jupiter and Saturn are very large in proportion to the Earth's orbit, these two planets appear much less magnified at their oppositions, or diminished at their conjunctions, than Mars does, in proportion to their mean apparent diameters.

CHAP. VII.

THE PHYSICAL CAUSES OF THE MOTIONS OF THE PLANETS—THE ECCENTRICITIES OF THEIR ORBITS—THE TIMES IN WHICH THE ACTION OF GRAVITY WOULD BRING THEM TO THE SUN—ARCHIMEDES'S IDEAL PROBLEM OF MOVING THE EARTH—THE WORLD NOT ETERNAL.

Gravitation and projection. Plate II. Fig. 4.

150. From the uniform projectile motion of bodies in straight lines, and the universal power of attraction which draws them off from these lines, the curvilineal motions of all the planets arise. If the body *A* be projected along the right line *ABX*, in open space, where it meets with no resistance, and is not drawn aside by any other power, it will for ever go on with the same velocity, and in the same direction. For the force which moves it from *A* to *B* in any given time, will carry it from *B* to *X* in as much more time, and so on, there being nothing to obstruct or alter its motion. But if, when this projectile force has carried it, suppose to *B*, the body *S* begins to attract it, with a power duly adjusted, and perpendicular to its motion at *B*, it will then be drawn from the straight line *ABX*, and forced to revolve about *S* in the circle *BYTU*.

Circular orbits.

When the body *A* comes to *U*, or any other part of its orbit, if the small body *u*, within the sphere of *U*'s attraction, be projected as in the right line *Z*, with a force perpendicular to the attraction of *U*, then *u* will go round *U* in the orbit *W*, and accompany it in its whole course round the body *S*. Here *S* may represent the Sun, *U* the Earth, and *u* the Moon.

151. If a planet at *B* gravitates, or is attracted, toward the Sun, so as to fall from *B* to *y* in the time that the projectile force would have carried it from *B* to *X*, it will describe the curve *B Y* by the combined action of these two forces, in the same time that the projectile force singly would have carried

it from *B* to *X*, or the gravitating power singly have caused it to descend from *B* to *y*; and these two forces being duly proportioned and perpendicular to each other, the planet obeying them both, will move in the circle *BYTU*.[5]

152. But if, whilst the projectile force would carry the planet from *B* to *b*, the Sun's attraction (which constitutes the planet's gravitation) should bring it down from *B* to 1, the gravitating power would then be too strong for the projectile force, and would cause the planet to describe the curve *B C*. When the planet comes to *C*, the gravitating power (which always increases as the square of the distance from the Sun *S* diminishes) will be yet stronger for the projectile force; and by conspiring in some degree therewith, will accelerate the planet's motion all the way from *C* to *K*, causing it to describe the arcs *B C*, *C D*, *D E*, *E F*, &c. all in equal times. Having its motion thus accelerated, it thereby gains so much centrifugal force, or tendency to fly off at *K* in the line *K k*, as overcomes the Sun's attraction; and the centrifugal force being too great to allow the planet to be brought nearer the Sun, or even to move round him in the circle *Klmn*, &c. it goes off, and ascends in the curve *KLMN*, &c. its motion decreasing as gradually from *K* to *B*, as it increased from *B* to *K*, because the Sun's attraction now acts against the planet's projectile motion just as much as it acted with it before. When the planet has got round to *B*, its projectile force is as much diminished from its mean state about *G* or *N*, as it was augmented at *K*; and so the Sun's attraction being more than sufficient to keep the planet from going off at *B*, it describes the same orbit over again, by virtue of the same forces or powers.[6]

Elliptical orbits.

[5] To make the projectile force balance the gravitating power so exactly, as that the body may move in a circle, the projectile velocity of the body must be such as it would have acquired by gravity alone, in falling through half the radius of the circle.

[6] If the planet at *B* is projected in the direction *BX*, with a velocity equal to that which it would acquire by falling through half the distance *BS*, by the action of the central body *S*, it will describe a circle round the centre *S*. If the velocity of projection be equal to that which the body would acquire by falling through a distance greater than one half of *BS*, it will move in an elliptical orbit, one of whose foci is *S*. If the velocity of the projectile be equal to that which it would acquire in falling through *BS*, its path will be a parabola, having *S* for its focus; and if the velocity be equal to that which it would acquire by falling through a space greater than *BS*, the body will move in a hyperbola.—*Ed.*

153. A double projectile force will always balance a quadruple power of gravity. Let the planet at *B* have twice as great an impulse from thence towards *X*, as it had before; that is, in the same length of time that it was projected from *B* to *b*, as in the last example, let it now be projected from *B* to *c*, and it will require four times as much gravity to retain it in its orbit; that is, it must fall as far as from *B* to 4 in the time that the projectile force would carry it from *B* to *C*, otherwise it could not describe the curve *BD*, as is evident by the figure. But, in as much time as the planet moves from *B* to *C* in the higher part of its orbit, it moves from *I* to *K*, or from *K* to *L*, in the lower part thereof, because, from the joint action of these two forces, it must always describe equal areas in equal times throughout its annual course. These areas are represented by the triangles *BSC*, *CSD*, *DSE*, *ESF*, &c. whose contents are equal to one another quite round the figure.

Fig. 4. The planets describe equal areas in equal times.

A difficulty removed.

154. As the planets approach nearer the Sun, and recede farther from him in every revolution, there may be some difficulty in conceiving the reason why the power of gravity, when it once gets the better of the projectile force, does not bring the planets nearer and nearer the Sun in every revolution, till they fall upon and unite with him; or why the projectile force, when it once gets the better of gravity, does not carry the planets farther and farther from the Sun, till it removes them quite out of the sphere of his attraction, and causes them to go on in straight lines for ever afterwards. But, by considering the effects of these powers as described in the two last articles, this difficulty will be removed. Suppose a planet at *B* to be carried by the projectile force as far as from *B* to *b*, in the time that gravity would have brought it down from *B* to 1, by these two forces it will describe the curve *BC*. When the planet comes down to *K*, it will be but half as far from the Sun *S* as it was at *B*; and therefore, by gravitating four times as strongly towards him, it would fall from *K* to *V* in the same length of time that it would have fallen from *B* to 1 in the higher part of its orbit; that is, through four times as much space; but its projectile force is then so much increased at *K*, as would carry it from *K* to *k* in the same time, being double of what it was at *B*, and is therefore too strong for the gravitating power, either to draw the planet to the Sun,

or cause it to go round him in the circle *Klmn*, &c. which would require its falling from *K* to *w*, through a greater space than gravity can draw it, whilst the projectile force is such as would carry it from *K* to *k*, and therefore the planet ascends in its orbit *KLMN*, decreasing in its velocity, for the causes already assigned in § 152.

155. The orbits of all the planets are ellipses, very little different from circles; but the orbits of the comets are very long ellipses, and the lower focus of them all is in the Sun. If we suppose the mean distance (or middle between the greatest and least) of every planet and comet from the Sun to be divided into 1000 equal parts, the eccentricities of their orbits,[7] both in such parts and in English miles will be as follow: Mercury's, 210 parts, or 6,720,000 miles; Venus's, 7 parts, or 413,000 miles; the Earth's, 17 parts, or 1,377,000 miles; Mars's, 93 parts, or 11,439,000 miles; Jupiter's, 48 parts, or 20,352,000 miles; Saturn's, 55 parts, or 42,735,000 miles. Of the nearest of the three fore-mentioned comets, 1,458,000 miles; of the middlemost, 2,025,000,000 miles; and of the outermost, 6,600,000,000.

The planetary orbits elliptical.

Their eccentricities.

156. By the above mentioned law, § 150 *et seq.* bodies will move in all kinds of ellipses, whether long or short, if the spaces they move in be void of resistance. Only those which move in the longer ellipses have so much the less projectile force impressed upon them in the higher parts of their orbits; and their velocities, in coming down towards the Sun, are so prodigiously increased by his attraction, that their centrifugal forces in the lower parts of their orbits are so great, as to overcome the Sun's attraction there, and cause them to ascend again towards the higher parts of their orbits; during which time the Sun's attraction, acting so contrary to the motions of those bodies, causes them to move slower and slower, until their projectile forces are diminished almost to nothing, and then they are brought back again by the Sun's attraction, as before.

The above laws sufficient for motions both in circular and elliptic orbits.

[7] The eccentricity of a planet or comet is the distance between the centre and focus of the elliptical orbit in which they move, or half the distance between the two foci. For more accurate numbers representing the eccentricities of the planets, see the table in the Supplement.—*Ed.*

In what times the planets would fall to the Sun by the power of gravity.

157. If the projectile forces of all the planets and comets were destroyed at their mean distances from the sun, their gravities would bring them down so, that Mercury would fall to the Sun in $15^d\ 13^h$; Venus in $39^d\ 17^h$; the Earth or Moon in $64^d\ 10^h$, Mars in 121 days; Jupiter in 290 days; Saturn in 767 days, and the Georgium Sidus in 5406 days. The nearest comet in 13,000 days; the middlemost in 23,000 days; and the outermost in 66,000 days. The Moon would fall to the Earth in $4^d\ 20^h$; Jupiter's first moon would fall to him in 7^h, his second in 15^h, his third in 30^h, and his fourth in 71^h. Saturn's first moon would fall to him in 8^h, his second in 12^h, his third in 19^h, his fourth in 68^h, and his fifth in 336^h. A stone would fall to the Earth's centre, if there were an hollow passage, in $21^m\ 9^s$. Mr. Whiston gives the following rule for such computations.[8] 'It is demonstrable, that half the period of any planet, when it is diminished in the sesquialteral proportion of the number 1 to the number 2, or nearly in the proportion of 1000 to 2828, is the time that it would fall to the centre of its orbit.' This proportion is, when a quantity or number contains another once and a half as much more.[9]

The prodigious attraction of the Sun and planets.

158. The quick motions of the moons of Jupiter and Saturn round their primaries, demonstrate that these two planets have stronger attractive powers than the Earth has: for, the stronger that one body attracts another, the greater must be the projectile force, and consequently the quicker must be the motion of that other body to keep it from falling to its primary or central planet. Jupiter's second moon is 124,000 miles farther from Jupiter than our moon is from us; and yet this second moon goes almost eight times round Jupiter whilst our moon goes only once round the Earth. What a prodigious attractive power must the Sun then have, to draw all the planets and satellites of the system towards him; and what an amazing power must it have

[8] Astronomical Principles of Religion, p. 66.

[9] The time in which any planet or comet would fall to the Sun, may be found more easily by dividing the time of half its revolution round the Sun by 2.82847, or by multiplying the time of a whole revolution by 0.176776. The squares of the times in which the planets would fall to the Sun are as the cubes of their distances.—*Ed.*

required to put all these planets and moons into such rapid motions at first! Amazing indeed to us, because impossible to be effected by the strength of all the living creatures in an unlimited number of worlds; but nowise hard for the Almighty, whose planetarium takes in the whole universe!

Archimedes's problem for raising the Earth.

159. The celebrated Archimedes affirmed he could move the Earth, if he had a place at a distance from it to stand upon to manage his machinery.[1] This assertion is true in theory, but, upon examination, will be found absolutely impossible in fact, even though a proper place and materials of sufficient strength could be had.

The simplest and easiest method of moving a heavy body a little way is by a lever or crow, where a small weight or power applied to the long arm will raise a great weight on the short one. But then, the small weight must move as much quicker than the great weight, as the latter is heavier than the former; and the length of the long arm of the lever must be in the same proportion to the length of the short one. Now, suppose a man to pull, or press the end of the long arm with the force of 200 pound weight, and that the Earth contains in round numbers, 4,000,000,000,000,000,000,000, or 4000 trillions of cubic feet, each at a mean rate weighing 100 pound; and that the prop or centre of motion of the lever is 6000 miles from the Earth's centre; in this case, the length of the lever from the fulcrum or centre of motion to the moving power or weight ought to be 12,000,000,000,000,000,000,000,000, or 12 quadrillions of miles; and so many miles must the power move, in order to raise the Earth but one mile; whence it is easy to compute, that if Archimedes, or the power applied, could move as swift as a cannon-bullet, it would take 27,000,000,000,000, or 27 billions of years to raise the Earth one inch.

If any other machine, such as a combination of wheels and screws, was proposed to move the Earth, the time it would require, and the space gone through by the hand that turned the machine, would be the same as before. Hence we may learn, that however boundless our imagination and theory may be, the actual operations of man are confined within narrow bounds, and more suited to our real wants than to our desires.

[1] Δὸ πῦ σῶ, καὶ τὸν κοσμον κινήσω, i. e. Give me a place to stand on, and I shall move the Earth!

Hard to determine what gravity is. 160. The Sun and planets mutually attract each other: the power by which they do so we call gravity. But whether this power be mechanical or not is very much disputed. Observation proves that the planets disturb one another's motions by it, and that it decreases according to the squares of the distances of the Sun and planets; as light, which is known to be material, likewise does. Hence, gravity should seem to arise from the agency of some subtle matter pressing towards the Sun and planets, and acting like all mechanical causes by contact. But, on the other hand, when we consider that the degree or force of gravity is exactly in proportion to the quantities of matter in those bodies, without any regard to their bulks or quantities of surface, acting as freely on their internal as external parts: it seems to surpass the power of mechanism, and to be either the immediate agency of the Deity, or affected by a law originally established and impressed on all matter by Him. But some affirm that matter, being altogether inert, cannot be impressed with any law even by Almighty power; and that the Deity, or some subordinate intelligence, must therefore be constantly impelling the planets toward the Sun, and moving them with the same irregularities and disturbances which gravity would cause, if it could be supposed to exist. But, if a man may venture to publish his own thoughts, it seems to me no more an absurdity, to suppose the Deity capable of infusing a law, or what laws he pleases into matter, than to suppose him capable of giving it existence at first. The manner of both is equally inconceivable to us, but neither of them imply a contradiction in our ideas; and what implies no contradiction is within the power of Omnipotence.

161. That the projectile force was at first given by the Deity is evident; for, since matter can never put itself in motion, and all bodies may be moved in any direction whatsoever; and yet the planets, both primary and secondary, move from West to East, in planes nearly coincident; whilst the comets move in all directions, and in planes very different from one another; these motions can be owing to no mechanical cause or necessity, but to the free will and power of an intelligent Being.

162. Whatever gravity be, it is plain that it acts every moment of time; for if its action should cease, the projectile force

would instantly carry off the planets in straight lines from those parts of their orbits where gravity left them. But, the planets being once put into motion, there is no occasion for any new projectile force, unless they meet with some resistance in their orbits; nor for any mending hand, unless they disturb one another too much by their mutual attractions.

The planets disturb one another's motions.

163. It is found that there are disturbances among the planets in their motions, arising from their mutual attractions when they are in the same quarter of the heavens; and the best modern observers find that our years are not always precisely of the same length.[2] Besides, there is reason to believe that the Moon is somewhat nearer the Earth now than she was formerly, her periodical month being shorter than it was in former ages. For our astronomical tables, which in the present age shew the times of solar and lunar eclipses to great precision, do not answer so well for very ancient eclipses. Hence it appears, that the Moon does not move in a medium void of all resistance, § 174; and therefore her projectile force being a little weakened, whilst there is nothing to diminish her gravity, she must be gradually approaching nearer the Earth, describing smaller and smaller circles round it in every revolution, and finishing her period sooner, although her absolute motion with regard to space be not so quick now as it was formerly, and therefore she must come to the Earth at last; unless that Being which gave her a sufficient projectile force at the beginning, adds a little more to it in due time.[3] And, as all the planets

The consequences thereof.

[2] If the planets did not mutually attract one another, the areas described by them would be exactly proportional to the times of description, § 153. But observations prove that these areas are not in such exact proportion, and are most varied when the greatest number of planets are in any particular quarter of the heavens. When any two planets are in conjunction, their mutual attractions, which tend to bring them nearer to one another, draws the inferior one a little farther from the Sun, and the superior one a little nearer to him, by which means the figure of their orbits is somewhat altered; but this alteration is too small to be discovered in several ages.

[3] The acceleration of the Moon's motion, to which Mr. Ferguson here alludes, amounts to about 11″ 8‴ in a century. It was generally ascribed to some resistance opposed to the motion of the Moon; but M. de la Place has lately discovered, that it arises from a diminution in the eccentricity of the Earth's orbit. This, as well as other irregularities in the solar system, generated by the mutual action of the planets, are all periodical: they are confined within narrow limits, and are balanced by irregularities of an equal and opposite kind. There is no possibility, therefore, of that general union of the planets in the centre of the system which our author apprehends.

move in spaces full of ether and light, which are material substances, they, too, must meet with some resistance; and, therefore, if their gravities are not diminished, nor their projectile forces increased, they must necessarily approach nearer and nearer the Sun, and at length fall upon and unite with him.

The world not eternal.

164. Here we have a strong philosophical argument against the eternity of the world. For, had it existed from eternity, and been left by the Deity to be governed by the combined actions of the above forces or powers, generally called laws, it had been at an end long ago; and if it be left to them, it must come to an end. But we may be certain that it will last as long as was intended by its Author, who ought no more to be found fault with for framing so perishable a work, than for making man mortal.

CHAP. VIII.

OF LIGHT—ITS PROPORTIONAL QUANTITIES ON THE DIFFERENT PLANETS—ITS REFRACTIONS IN WATER AND AIR—THE ATMOSPHERE—ITS WEIGHT AND PROPERTIES—THE HORIZONTAL MOON.

165. LIGHT consists of exceedingly small particles of matter, issuing from a luminous body; as from a lighted candle, such particles of matter constantly flow in all directions. Dr. Niewentyt[1] computes, that in one second of time

By the most simple law, the diminution of gravity, as the square of the distance increases, the planets are not only retained in their orbits, when whirling round a central Sun, but an eternal stability is insured to the solar system. The little derangements which affect the motions of the heavenly bodies are apparent only to the eye of the astronomer; and even these, after reaching a certain limit, gradually diminish, till the system, regaining its balance, returns to that state of harmony and order which preceded the commencement of these secular inequalities. Even amidst the changes and inequalities of the system, the general harmony is always apparent; and those partial and temporary derangements which, to vulgar minds, may seem to indicate a progressive decay, serve only to evince the stability and permanence of the whole. In the contemplation of such a scene, every unperverted mind must be struck with that astonishing wisdom which framed the various parts of the universe, and bound them together by one simple law.—*Ed.*

[1] *Religious Philosopher*, vol. iii, p. 65.

there flows 418,660,000,000,000,000,000,000,000,000,000,000,000,000,000 particles of light out of a burning candle, which number contains at least 6,337,242,000,000 times the number of grains of sand in the whole Earth, supposing 100 grains of sand to be equal in length to an inch, and consequently every cubic inch of the Earth to contain 1,000,000 of such grains.

The amazing smallness of the particles of light.

166. These amazingly small particles, by striking upon our eyes, excite in our minds the idea of light; and, if they were as large as the smallest particles of matter discernible by our best microscopes, instead of being serviceable to us, they would soon deprive us of sight by the force arising from their immense velocity, which is above 164,000 miles every second, (see chap. xi) or 1,230,000 times swifter than the motion of a cannon-bullet.[2] And therefore, if the particles of light were so large, that 1,000,000 of them were equal in bulk to an ordinary grain of sand, we durst no more open our eyes to the light, than suffer sand to be shot point blank against them.

The dreadful effects that would ensue from their being larger.

167. When these small particles, flowing from the sun or from a candle, fall upon bodies, and are thereby reflected to our eyes, they excite in us the idea of that body, by forming its picture on the retina.[3] And since bodies are visible on all sides, light must be reflected from them in all directions.

How objects become visible to us.

168. A ray of light is a continued stream of these particles, flowing from any visible body in a straight line. That the rays move in straight, and not in crooked lines, unless they be refracted, is evident from bodies not being visible if we endeavour to look at them through the bore of a bended pipe; and, from their ceasing to be seen by the interposition of other bodies, as the fixed stars by the interposition of the Moon and planets, and the Sun wholly or in part by the interposition of the Moon, Mercury, or

The rays of light naturally move in straight lines.

[2] As the mean distance of the Sun from the Earth is nearly 95,000,000 English miles, and as light moves through this space in 8′ 7″, its velocity per second will be 195,072 English miles, which is about 10,313 times greater than the mean velocity of the Earth in its orbit.—*Ed.*

[3] A fine net-work membrane in the bottom of the eye. Some philosophers have maintained, that the choroid coat, situated behind the retina, is the seat of vision. The sensation is conveyed from the seat of vision to the brain by the optic nerves, which enter the back part of the eye.—*Ed.*

A proof that they hinder not one another's motions.

Venus. And that these rays do not interfere, or jostle one another out of their ways, in flowing from different bodies all around, is plain from the following experiment. Make a little hole in a thin plate of metal, and set the plate upright on a table, facing a row of lighted candles standing by one another; then place a sheet of paper or pasteboard at a little distance from the other side of the plate, and the rays of all the candles, flowing through the hole, will form as many specks of light on the paper as there are candles before the plate, each speck as distinct and large as if there were only one candle to cast one speck, which shews that the rays are no hindrance to each other in their motions, although they all cross in the hole.

169. Light, and therefore heat, so far as it depends on the Sun's rays (§ 85, towards the end), decreases in proportion to the squares of the distances of the planets from the Sun. This is easily demonstrated by a figure which, together with its description, I have taken from Dr. Smith's optics (book i, art. 57).

Plate II. Fig. 11.

Let the light which flows from a point *A*, and passes through a square hole *B*, be received upon a plane *C*, parallel to the plane of the hole; or, if you please, let the figure *C* be the shadow of the plane *B*; and when the distance of *C* is double of *B*, the length and breadth of the shadow

In what proportion light and heat decrease at any given distance from the Sun.

C will be each double of the length and breadth of the plane *B*, and treble when *AD* is treble of *AB*, and so on, which may be easily examined by the light of a candle placed at *A*. Therefore the surface of the shadow *C*, at the distance *AC* double of *AB*, is divisible into 4 squares, and at a treble distance, into 9 squares, severally equal to the square *B*, as represented in the figure. The light then which falls upon the plane *B* being suffered to pass to double that distance, will be uniformly spread over 4 times the space, and consequently will be 4 times thinner in every part of that space, and at a treble distance it will be 9 times thinner; and at a quadruple distance, 16 times thinner than it was at first, and so on, according to the increase of the square surfaces *B*, *C*, *D*, *E*, built upon the distances *AB*, *AC*, *AD*, *AE*. Consequently, the quantities of this rarefied light received upon a surface of any given size and shape whatever, removed successively to these several distances, will be but $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$ of the whole quantity received by it at the

first distance *AB*. Or, in general words, the densities and quantities of light received upon any given plane, are diminished in the same proportion as the squares of the distances of that plane, from the luminous body, are increased; and, on the contrary, are increased in the same proportion as these squares are diminished.[4]

Why the planets appear dimmer when viewed through telescopes than by the bare eye.

170. The more a telescope magnifies the discs of the Moon and planets, they appear so much dimmer than to the bare eye, because the telescope cannot magnify the quantity of light as it does the surface; and, by spreading the same quantity of light over a surface so much larger than the naked eye beheld, just so much dimmer must it appear when viewed by a telescope than by the bare eye.[5]

171. When a ray of light passes out of one medium into another,[6] it is refracted or turned out of its first course, more or less, as it falls more or less obliquely on the refracting surface which divides the two mediums. This may be proved by several experiments, of which we shall only give three for example's sake. 1, In a basin *FGH* put a piece of money as *DB*, and then retire from it as to *A*, till the edge of the bason at *E* just hides the money from your sight; then, keeping your head steady, let another person fill the basin gently with water. As he fills it, you will see more and more of the piece *DB*, which will be all in view when the basin is full, and appear as if lifted up to *C*. For the ray *AEB*, which was straight whilst the basin was empty, is now bent at the surface of the water in *E*, and turned out of its rectilineal course into the direction

Fig. 8.

Refraction of the rays of light.

4 This proposition is true only when the given plane is perpendicular to the direction of the light which falls upon it; for, when the plane is inclined to this direction, the density and quantity of light or heat is diminished, and this diminution is proportional to the cosine of the angle of inclination.—*Ed.*

5 This position has been controverted by Dr. Herschel, who maintains, that telescopes have a *penetrating power*. In a dark night, when the eye could not penetrate far into space, his 20 feet telescope shewed the clock on a distant steeple when the naked eye could not see the steeple itself. The penetrating power depends upon the quantity of reflected or refracted light upon the apertures of the mirrors or lenses, and the size of the pupil. See Phil. Trans. 1800, Part 1.—*Ed.*

6 A medium, in this sense, is any transparent body, or that through which the rays of light can pass, as water, glass, diamond, air, and even a vacuum is sometimes called a medium.

ED. Or, in other words, the ray *DEK*, that proceeded in a straight line from the edge *D* whilst the basin was empty, and went above the eye at *A*, is now bent at *E*; and instead of going on in the rectilineal direction *DEK*, goes in the angled direction *DEA*, and by entering the eye at *A*, renders the object *DB* visible. Or, 2, Place the basin where the Sun shines obliquely, and observe where the shadow of the rim *E* falls on the bottom as at *B*, then fill it with water, and the shadow will fall at *D*; which proves, that the rays of light, falling obliquely on the surface of the water, are refracted, or bent downwards into it.

172. The less obliquely the rays of light fall upon the surface of any medium, the less they are refracted; and if they fall perpendicularly thereon, they are not refracted at all. For, in the last experiment, the higher the Sun rises, the less will be the difference between the places where the edge of the shadow falls in the empty and full basin And, 3, If a stick be laid over the basin, and the Sun's rays being reflected perpendicularly into it from a looking glass, the shadow of the stick will fall upon the same place of the bottom, whether the bason be full or empty.

173. The denser that any medium is, the more is light refracted in passing through it.

The atmosphere. 174. The Earth is surrounded by a thin fluid mass of matter, called the air or atmosphere, which gravitates to the Earth, revolves with it in its diurnal motion, and goes round the Sun with it every year. This fluid is of an elastic or springy nature, and its lowermost parts being compressed by the weight of all the air above them, are pressed the closer together, and are therefore densest of all at the Earth's surface, and gradually rarer the higher up. It is well known (*Newton's System of the World*, p. 120,) that the air near the surface of our Earth possesses a space about 1200 times greater than water of the same weight.[7] And therefore, a cylindric column of air 1200 feet high, is of equal weight with a cylinder of water of the same breadth, and but one foot high. But a cylinder of air reaching to the top of the atmosphere is of equal weight with a cylinder of water about 33 feet high;[8] and there-

[7] Air is only 900 times denser than water.—*Ed.*

[8] This is evident from common pumps.

fore, if from the whole cylinder of air, the lower part of 1200 feet high is taken away, the remaining upper part will be of equal weight with a cylinder of water 32 feet high; wherefore, at the height of 1200 feet, or two furlongs, the weight of the incumbent air is less, and consequently the rarity of the compressed air is greater than near the Earth's surface, in the ratio of 33 to 32. And the air at all heights whatsoever, supposing the expansion thereof to be reciprocally proportional to its compression; and this proportion has been proved by the experiments of Dr. Hooke and others. The result of the computation I have set down in the annexed table; in the first column of which you have the height of the air in miles, whereof 4000 make a semi-diameter of the Earth; in the second the compression of the air, or the incumbent weight; in the third, its rarity or expansion, supposing gravity to decrease in the duplicate ratio of the distances from the Earth's centre. And the small numeral figures are here used, to shew what number of cyphers must be joined to the numbers expressed by the larger figures, as $0.^{17}1224$ for 0.000000000000000001224 and 26956^{15} for 26956000000000000000.

TABLE OF THE AIR'S COMPRESSION AND RARITY AT DIFFERENT HEIGHTS.

	Air's	
Height.	*Compression.*	*Expansion.*
0	33	. . 1
5	17.8515 . .	. . 1.8486
10	9.6717 . .	. . 3.4151
20	2.852 . .	. . 11.571
40	0.2525 . .	. 136.83
400	$0.^{17}1224$.	. 26956^{15}
4000	$0.^{105}4465$	. $7[illegible]907^{102}$
40000	$0.^{192}1628$	. 26263^{189}
400000	$0.^{210}7895$	. 41798^{207}
4000000	$0.^{212}9878$	. $3[illegible]414^{209}$
Infinite.	$0.^{212}9941$	. 54622^{209}

From the above table, it appears that the air in proceeding upwards is rarefied in such a manner, that a sphere of that air

which is nearest the Earth, but of one inch diameter, if dilated to an equal rarefaction with that of the air at the height of 10 semi-diameters of the Earth, would fill up more space than is contained in the whole heavens on this side the fixed stars. And it likewise appears that the Moon does not move in a perfectly free and unresisting medium, although the air, at a height equal to her distance, is at least 3400^{142} times thinner than at the Earth's surface, and therefore cannot resist her motion so as to be sensible in many ages.

Its weight how found. 175. The weight of the air at the Earth's surface is found by experiments made with the air-pump, and also by the quantity of mercury that the atmosphere balances in the barometer, in which, at a mean state, the mercury stands 29½ inches high. And if the tube were a square inch wide, it would at that height contain 29½ cubic inches of mercury, which is just 15 pound weight; and so much weight of air every square inch of the Earth's surface sustains; and every square foot 144 times as much, because it contains 144 square inches. Now, as the Earth's surface contains, in round numbers, 200,000,000 square miles, it must contain no less than 5,575,680,000,000,000 square feet; which, being multiplied by 2160, the number of pounds on each square foot amounts to 12,043,468,800,000,000,000 pounds for the weight of the whole atmosphere. At this rate, a middle-sized man, whose surface is about 15 square feet, is pressed by 32,400 pound weight of air all around; for fluids press equally up and down, and on all sides. But, because this enormous weight is equal on all sides, and counterbalanced by the spring of the air diffused through all parts of our bodies, it is not in the least degree felt by us.

A common mistake about the weight of the air. 176. Oftentimes the state of the air is such, that we feel ourselves languid and dull; which is commonly thought to be occasioned by the air's being foggy and heavy about us. But that the air is then too light, is evident from the mercury's sinking in the barometer, at which time it is generally found that the air has not sufficient strength to bear up the vapours which compose the clouds: for, when it is otherwise, the clouds mount high, and the air is more elastic and weighty about us, by which means it balances the internal spring of the air within us, braces up our blood-vessels and nerves, and makes us brisk and lively.

177. According to Dr. Keill (*Astronomy*, p. 232), and other astronomical writers, it is entirely owing to the atmosphere that the heavens appear bright in the day time. For, without an atmosphere, only that part of the heavens would shine in which the Sun was placed: and if we could live without air, and should turn our backs toward the Sun, the whole heavens would appear as dark as in the night, and the stars would be seen as clear as in the nocturnal sky. In this case we should have no twilight; but a sudden transition from the brightest sunshine to the blackest darkness immediately after sun-set; and from the blackest darkness to the brightest sunshine at sun-rising; which would be extremely inconvenient, if not blinding, to all mortals. But, by means of the atmosphere, we enjoy the Sun's light, reflected from the aerial particles, for some time before he rises and after he sets. For, when the Earth, by its rotation, has withdrawn our sight from the Sun, the atmosphere being still higher than we are, has the Sun's light imparted to it; which gradually decreases until he has got 18 below the horizon; and then, all that part of the atmosphere which is above us is dark. From the length of twilight, the Doctor has calculated the height of the atmosphere (so far as it is dense enough to reflect any light) to be about 44 miles. But it is seldom dense enough at two miles height to bear up the clouds.

Without an atmosphere the heavens would always appear dark, and we should have no twilight.

178. The atmosphere refracts the Sun's rays so as to bring him in sight every clear day, before he rises in the horizon; and to keep him in view for some minutes after he is really set below it. For, at some times of the year, we see the Sun 10 minutes longer above the horizon than he would be if there were no refractions: and about 6 minutes every day, at a mean rate

It brings the Sun in view before he rises, and keeps him in view after he sets.

179. To illustrate this, let *I E K* be a part of the Earth's surface, covered with the atmosphere *H G F C*; and let *H E O* be the sensible horizon[9] of an observer at E. When the Sun is at *A*, really below the horizon, a ray of light *A C* proceeding from him comes straight to *C*, where it falls on the surface of the atmosphere, and there entering a denser medium, it is turned out of its rectilineal course *A C d G*

Fig. 9.

[9] As far as one can see round him on the earth.

and bent down to the observer's eye at *E*; who then sees the Sun in the direction of the refracted ray *E d c*, which lies above the horizon, and being extended out to the heavens, shews the Sun at *B*, § 171.

180. The higher the Sun rises, the less his rays are refracted, because they fall less obliquely on the surface of the atmosphere, § 172. Thus, when the Sun is in the direction of the line *E f L* continued, he is so nearly perpendicular to the surface of the earth at *E*, that his rays are but very little bent from a rectilineal course.

The quantity of refraction.

181. The Sun is about $32\frac{1}{10}'$ of a degree in breadth, when at his mean distance from the Earth; and the horizontal refraction of his rays is $33\frac{9}{10}'$, which, being more than his whole diameter, brings all his disc in view, when his uppermost edge rises in the horizon. At 10° height, the refraction is a little more than 5′; at 20 only 2′ 35″; at 30 but 1′ 38″; between which and the zenith it is scarce sensible: the quantity throughout is shewn by the annexed table.[1]

[1] Instead of Sir Isaac Newton's table of refractions, which was published in all the former editions of this work, and was very inaccurate, we have inserted a new table, founded upon the correct observations of Dr. Bradley, and suited to a mean state of the atmosphere, when the barometer is at 30.00, and Fahrenheit's thermometer at 55°. If the barometer be higher than 30°, and the thermometer lower than 55°, the refraction is greater than that which the table assigns; and if the barometer be lower than 30°, and the thermometer higher than 55°, the refraction assigned by the table is too small. In low altitudes, this variation in the refraction, arising from a variation in the state of the atmosphere, is very considerable; but when the altitude exceeds 60°, it may be safely neglected.—*Ed.*

182. *A Table shewing the Refractions of the Sun, Moon, and Stars, adapted to their apparent Altitudes, and to a mean state of the Atmosphere, when the Barometer is at 30.00, and the Thermometer of Fahrenheit at 55°.*

Appar. Alt.	Refraction.	Ap. Alt.	Refraction.	Ap. Alt.	Refraction.
D. M.	M. S.	D.	M. S.	D.	M. S.
0 0	32 54	21	2 27	56	0 38
0 15	30 30	22	2 20	57	0 37
0 30	28 17	23	2 13	58	0 35
0 45	26 16	24	2 7	59	0 34
1 0	24 24	25	2 1	60	0 33
1 15	22 43	26	1 56	61	0 32
1 30	21 11	27	1 51	62	0 30
1 45	19 47	28	1 46	63	0 29
2 0	18 31	29	1 42	64	0 28
2 30	16 20	30	1 38	65	0 26
3 0	14 32	31	1 34	66	0 25
3 30	13 3	32	1 31	67	0 24
4 0	11 48	33	1 27	68	0 23
4 30	10 45	34	1 24	69	0 22
5 0	9 51	35	1 21	70	0 20
5 30	9 5	36	1 18	71	0 19
6 0	8 25	37	1 15	72	0 18
6 30	7 50	38	1 13	73	0 17
7 0	7 20	39	1 10	74	0 16
7 30	6 53	40	1 8	75	0 15
8 0	6 29	41	1 5	76	0 14
8 30	6 7	42	1 3	77	0 13
9 0	5 48	43	1 1	78	0 12
9 30	5 30	44	0 59	79	0 11
10 0	5 14	45	0 57	80	0 10
11 0	4 46	46	0 55	81	0 9
12 0	4 23	47	0 53	82	0 8
13 0	4 2	48	0 51	83	0 7
14 0	3 45	49	0 49	84	0 6
15 0	3 30	50	0 47	85	0 5
16 0	3 16	51	0 46	86	0 4
17 0	3 4	52	0 44	87	0 3
18 0	2 54	53	0 42	88	0 2
19 0	2 44	54	0 41	89	0 1
20 0	2 35	55	0 39	90	0 0

183. In all observations, to have the true altitude of the Sun, Moon, or stars, the refraction must be subtracted from the observed altitude.[2] But the quantity of refraction is not always the same at the same altitude; because heat diminishes the air's refractive power and density, and cold increases both; and, therefore, no one table can serve precisely for the same place at all seasons, nor even at all times of the same day; much less for different climates; it having been observed, that the horizontal refractions are near a third part less at the equator than at Paris, as mentioned by Dr. Smith in the 370th remark on his Optics, where the following account is given of an extraordinary refraction of the Sun-beams by cold:—'There is a famous observation of this kind made by some Hollanders that wintered in Nova Zembla in the year 1596, who were surprised to find, that, after a continual night of 3 months, the Sun began to rise 17 days sooner than according to computation, deduced from the altitude of the pole, observed to be 76: which cannot otherwise be accounted for, than by an extraordinary refraction of the Sun's rays, passing through the cold dense air in that climate. Kepler computes, that the Sun was almost 5 below the horizon when he first appeared; and, consequently, the refraction of his rays was about 9 times greater than it is with us.'

The inconstancy of refractions.

A very remarkable case concerning refraction.

Plate II. Fig. 10.

184. The Sun and Moon appear of an oval figure, as *FCGD*, just after their rising, and before their setting: the reason is, that the refraction being greater in the horizon than at any distance above it, the lowermost limb *G* appears more elevated than the uppermost. But, although the refraction shortens the vertical diameter *FG*, it has no sensible effect on the horizontal diameter *CD*, which is all equally elevated. When the refraction is so small as to be imperceptible, the Sun and Moon appear perfectly round, as *AEBF*.

Our imagination cannot judge rightly of the distance of inaccessible objects.

185. We daily observe, that the objects which appear most distinct are generally those which are nearest to us; and, consequently, when we have nothing but our imagination to assist us in estimating distances, bright objects seem nearer to us than those

[2] The observed altitude of the celestial bodies must also be corrected by the application of parallax.—*Ed.*

which are less bright, or than the same objects do when they appear less bright and worse defined, even though their distance in both cases be the same. And if, in both cases, they are seen under the same angle,[3] our imagination naturally suggests an idea of a greater distance between us and those objects which appear fainter and worse defined, than those which appear brighter under the same angles; especially if they be such objects as we were never near to, and of whose real magnitudes we can be no judges by sight.

186. But, it is not only in judging of the different apparent magnitudes of the same objects, which are better or worse defined by their being more or less bright, that we may be deceived: for we may make a wrong conclusion even when we view them under equal degrees of brightness, and under equal angles; although they be objects whose bulks we are generally acquainted with, such as houses or trees: for proof of which, the two following instances may suffice.

Nor always of those which are accessible.

[3] An angle is the inclination of two right lines, as *I H* and *K H*, meeting in a point at *H*; and in describing an angle by three letters, the middle letter always denotes the angular point; thus, the above lines *I H* and *K H* meeting each other at *H*, make the angle *I H K*. And the point *H* is supposed to be the centre of a circle, the circumference of which contains 360 equal parts, called degrees. A fourth part of a circle, called a quadrant, as *G E*, contains 90°; and every angle is measured by the number of degrees in the arc it cuts off; as the angle *E H P* is 45°, the angle *E H F* 33°, &c. and so the angle *E H F* is the same with the angle *C H N*, and also with the angle *A H M*, because they all cut off the same arc or portion of the quadrant *E G*; but the angle *E H F* is greater than the angle *C H D* or *A H L*, because it cuts off a greater arc. Plate II, Fig. 5.

The nearer an object is to the eye, the bigger it appears, and under the greater angle is it seen. To illustrate this a little, suppose an arrow in the position *IK*, perpendicular to the right line *HA*, drawn from the eye at *H* through the middle of the arrow at *O*. It is plain that the arrow is seen under the angle *IHK*, and that *HO*, which is its distance from the eye, divides into halves both the arrow and the angle under which it is seen, viz. the arrow into *IO*, *OK*, and the angle into *IHO* and *KHO*: and this will be the case whatever distance the arrow is placed at. Let now three arrows, all of the same length with *IK*, be placed at the distances *HA*, *HC*, *HE*, still perpendicular to, and bisected by, the right line *HA*; then will *AB*, *CD*, *EF*, be equal to, and represent *OI*; and *AB* (the same as *OI*) will be seen from *H* under the angle *AHB*; but *CD* (the same as *OI*) will be seen under the angle *CHD* or *AHL*; and *EF* (the same as *OI*) will be seen under the angle *EHF*, or *CHN*, or *AHM*. Also *EF* or *OI* at the distance *HE* will appear as long as *ON* would at the distance *HC*, or as *AM* would at the distance *HA*; and *CD* or *IO* at the distance *HC* will appear as long as *AL* would at the distance *HA*. So that as an object approaches the eye, both its magnitude and the angle under which it is seen increase; and as the object recedes, the contrary.

The reason assigned.

First, When a house is seen over a very broad river by a person standing on low ground, who sees nothing of the river, nor knows of it beforehand, the breadth of the river being hid from him, because the banks seem contiguous, he loses the idea of a distance equal to that breadth; and the house seems small, because he refers it to a less distance than it really is at. But, if he goes to a place from which the river and interjacent ground can be seen, though no farther from the house, he then perceives the house to be at a greater distance than he imagined; and therefore fancies it to be bigger than he did at first; although in both cases it appears under the same angle, and, consequently, makes no bigger picture on the retina of his eye in the latter case than it did in the former. Many have been deceived, by taking a red coat of arms, fixed upon the iron gate in Clare-hall walks at Cambridge, for a brick house at a much greater distance.[4]

Secondly, In foggy weather, at first sight, we generally imagine a small house, which is just at hand, to be a great castle at a distance; because it appears so dull and ill defined, when seen through the mist, that we refer it to a much greater distance than it really is at; and, therefore, under the same angle, we judge it to be much bigger. For, the near object *FE*, seen by the eye *ABD*, appears under the same angle *GCH* that the remote object *GHI* does: and the rays *GFCN* and *HECM* crossing one another at *C* in the pupil of the eye, limit the size of the picture *MN* on the retina; which is the picture of the object *FE*, and if *FE* were taken away, would be the picture of the object *GHI*, only worse defined; because *GHI*, being farther off, appears duller and fainter than *FE* did. But when a fog, as *KL*, comes between the eye and the object *FE*, the object appears

Fig. 12.

[4] The fields which are beyond the gate rise gradually till they are just seen over it; and the arms being red, are often mistaken for a house at a considerable distance in those fields.

I once met with a curious deception in a gentleman's garden at Hackney, occasioned by a large pane of glass in the garden wall at some distance from his house. The glass (through which the sky was seen from low ground) reflected a very faint image of the house; but the image seemed to be in the clouds near the horizon, and at that distance looked as if it were a huge castle in the air. Yet, the angle under which the image appeared, was equal to that under which the house was seen: but the image being mentally referred to a much greater distance than the house, appeared much bigger to the imagination.

dull and ill defined like *G H I*; which causes our imagination to refer *F E* to the greater distance *C H*, instead of the small distance *C E* which it really is at. And, consequently, as misjudging the distance does not in the least diminish the angle under which the object appears, the small hay rick *F E* seems to be as big as *G H I*.

187. The Sun and Moon appear bigger in the horizon than at any considerable height above it. These luminaries, although at great distances from the Earth, appear floating, as it were, on the surface of our atmosphere *HGFfeC*, a little way beyond the clouds; of which those about *F*, directly over our heads at *E*, are nearer us than those about *H* or *e* in the horizon *H E e*. Therefore, when the Sun or Moon appears in the horizon at *e*, they are not only seen in a part of the sky which is really farther from us than if they were at any considerable altitude, as about *f*; but they are also seen through a greater quantity of air and vapours at *e* than at *f*. Here we have two concurring appearances which deceive our imagination, and cause us to refer the Sun and Moon to a greater distance at their rising or setting about *e*, than when they are considerably high, as at *f*: first, their seeming to be on a part of the atmosphere at *e*, which is really farther than *f* from a spectator at *E*; and, secondly, their being seen through a grosser medium when at *e*, than when at *f*; which, by rendering them dimmer, causes us to imagine them to be at a yet greater distance. And as, in both cases, they are seen[5] much under the same angle, we naturally judge them to be biggest when they seem farthest from us; like the above-mentioned house, § 186, seen from a higher ground, which shewed it to be farther off than it appeared from low ground; or the hay rick, which appeared at a greater distance by means of an interposing fog.

Why the Sun and Moon appear biggest in the horizon.

Fig. 9.

188. Any one may satisfy himself that the Moon appears under no greater angle in the horizon than on the meridian, by taking a large sheet of paper, and rolling it up in the form of a tube, of such a width, that, observing the Moon through it when she rises, she may, as it were, just fill the tube; then

Their apparent diameters are not less on the meridian than in the horizon.

[5] The Sun and Moon subtend a greater angle on the meridian than in the horizon, being nearer the observer's place when they are in the meridian, by the whole semidiameter of the Earth.

tie a thread round it, to keep it of that size; and when the Moon comes to the meridian, and appears much less to the eye, look at her again through the same tube, and she will fill it just as much, if not more, than she did at her rising.

189. When the full Moon is in *perigee*, or at her least distance from the Earth, she is seen under a larger angle, and must therefore appear bigger than when she is full at other times; and if that part of the atmosphere where she rises be more replete with vapours than usual, she appears so much the dimmer; and, therefore, we fancy her to be still bigger, by referring her to an unusually great distance; knowing that no objects which are very far distant can appear big unless they be really so.

CHAP. IX.

THE METHOD OF FINDING THE DISTANCES OF THE SUN, MOON, AND PLANETS.

190. THOSE who have not learned how to take the[1] altitude of any celestial object by a common quadrant, nor know any thing of plain trigonometry, may pass over the first article of this short chapter, and take the astronomer's word for it, that

[1] The altitude of any celestial object is an arc of the sky intercepted between the horizon and the object. In Fig. 6 of Plate II. let *H O X* be a horizontal line, supposed to be extended from the eye at *A* to *X*, where the sky and Earth seem to meet at the end of a long and level plain; and let *S* be the Sun. The arc *X Y* will be the Sun's height above the horizon at *X*, and is found by the instrument *E C D*, which is a quadrantal board, or plate of metal, divided into 90 equal parts or degrees on its limb *D P C*; and has a couple of little brass plates, as *a* and *b*, with a small hole in each of them, called *sight-holes*, for looking through, parallel to the edge of the quadrant whereon they stand. To the centre *E* is fixed one end of a thread *F*, called the *plumb line*, which has a small weight or plumet *P* fixed to its other end. Now, if an observer holds the quadrant upright, without inclining it to either side, and so that the horizon at *X* is seen through the sight holes *a* and *b*, the plumb line will cut or hang over the beginning of the degrees at 0, in the edge *E C*; but if he elevates the quadrant so as to look through the sight holes at any part of the heavens, suppose the Sun at *S*; just so many degrees as he elevates the sight hole *b* above the horizontal line *H O X*, so many degrees will the plumb line cut in the limb *C P* of the quadrant. For, let the observer's eye at *A* be in the centre of the celestial arc *X Y V* (and he may be said to be in the centre of the Sun's apparent diurnal orbit, let him be on what part of the Earth he will), in which are the Sun is at that time, suppose 25° high, and let the observer hold the quadrant so that he may see the Sun through the sight holes; the plumb line freely playing on the quadrant will cut the 25° in the limb *C P*,

the distances of the Sun and planets are as stated in the first chapter of this book. But, to every one who knows how to take the altitude of the Sun, the Moon, or a star, and can solve a plain right angled triangle, the following method of finding the distances of the Sun and Moon, will be easily understood.

Let *B A G* be one-half of the Earth, *A C* its semidiameter, *S* the Sun, *m* the Moon, and *E K O L* a quarter of the circle described by the Moon in revolving from the meridian to the meridian again. Let *C R S* be the rational horizon of an observer at *A*, extended to the Sun in the heavens; and *H A O* his sensible horizon, extended to the Moon's orbit. *A L C* is the angle under which the Earth's semidiameter *A C* is seen from the Moon at *L*, which is equal to the angle *O A L*, because the right lines *A O* and *C L*, which include both these angles, are parallel. (*Euclid*, book I, prop. 29.) *A S C* is the angle under which the Earth's semidiameter *A C* is seen from the Sun at *S*, and is equal to the angle *O A f*, because the lines *A O* and *C R S* are parallel. Now, it is found by observation, that the angle *O A L* is much greater than the angle *O A f*; but *O A L* is equal to *A L C*, and *O A f* is equal to *A S C*. Now, as *A S C* is much less than *A L C*, it proves that the Earth's semidiameter *A C* appears much greater as seen from the Moon at *L*, than from the Sun at *S*; and, therefore, the Earth is much farther from the Sun than from the Moon. (Note on § 185). The quantities of these angles may be determined by observation in the following manner.

Plate IV. Fig. 1.

Let a graduated instrument, as *D A E* (the larger the better), having a moveable index with sight-holes, be fixed in such a manner, that its plane surface may be parallel to the plane of the equator, and its edge *A D* in the meridian: so that when the

equal to the number of degrees of the Sun's altitude at the time of observation.*

N. B. Whoever looks at the Sun must have a smoked glass before his eyes to save them from hurt. The better way is not to look at the Sun through the sight holes, but to hold the quadrant facing the eye, at a little distance, and so that the Sun shining through one hole, the ray may be seen to fall on the other.

* Those who know so much of mathematics, as that the three angles of every triangle are equal to two right angles (*Euclid*, b. I, prop. 32), will easily understand how the quadrant gives us the altitude of any celestial body. Since *H O X* is a horizontal line, and *L F P* perpendicular to the horizon, *A H* [illegible] will be a right angled triangle, and the two angles *A E H*, *H A E*, equal to a right angle. But as *A E C* is a right angle, *A E H* and *H E C* are together equal to a right angle. From each of these take the angle *A E H*, and the remainder, *H E C*, or *P F C*, will be equal to *H A E* the altitude of the celestial body *S*.—*Ed.*

Moon is in the equinoctial, and on the meridian *A D E*, she may be seen through the sight-holes, when the edge of the moveable index cuts the beginning of the divisions at 0, on the graduated limb *D E*; and when she is so seen, let the *precise* time be noted. Now, as the Moon revolves about the Earth, from the meridian to the meridian again, in about $24^h\ 48^m$, she will go a fourth part round it in a fourth part of that time, viz. in $6^h\ 12^m$, as seen from *C*, that is, from the Earth's centre or pole. But as seen from *A*, the observer's place on the Earth's surface, the Moon will seem to have gone a quarter round the Earth when she comes to the sensible horizon at *O*; for the index, through the sights of which she is then viewed, will be at *d*, 90° from *D*, where it was when she was seen at *E*. Now, let the exact moment when the Moon is seen at *O* (which will be when she is in or near the sensible horizon) be carefully noted,[2] that it may be known in what time she has gone from *E* to *O*; which time subtracted from $6^h\ 12^m$ (the time of her going from *E* to *L*), leaves the time of her going from *O* to *L*, and affords an easy method for finding the angle *O A L* (called *the Moon's horizontal parallax*, which is equal to the angle *A L C*) by the following analogy: as the time of the Moon's describing the arc *E O* is to 90°, so is $6^h\ 12^m$ to the degrees of the arc *D d E*, which measures the angle *E A L*; from which subtract 90°, and there remains the angle *O A L*, equal to the angle *A L C*, under which the Earth's semidiameter *A C* is seen from the Moon. Now, since all the angles of a right-lined triangle are equal to 180°, or to two right angles, and the sides of a triangle are always proportional to the sines of the opposite angles, say, by *the rule of three*, as the sine of the angle *A L C* at the Moon *L* is to its opposite side *A C*, the Earth's semidiameter, which is known to be 3,985 miles, so is radius, viz. the sine of 90°, or of the right angle *A L C*, to its opposite side *A D*, which is the Moon's distance at *L* from the observer's place at *A* on the Earth's surface; or, so is the sine of the angle *C A L* to its opposite side *C L*, which is the Moon's distance from the Earth's centre, and comes out at a mean rate to be 240,000 miles. The angle *C A L* is equal to what *O A L* wants of 90°.

The Moon's horizontal parallax, what.

The Moon's distance determined.

[2] Here proper allowance must be made for the refraction, which being about 33 minutes of a degree in the horizon, will cause the Moon's centre to appear 33 minutes above the horizon when her centre is really in it.

191. The Sun's distance from the Earth might be found the same way, though with more difficulty, if his horizontal parallax, or the angle *O A S*, equal to the angle *A S C*, were not so small, as to be hardly perceptible, being scarce 10″, or the 360th part of a degree. But the Moon's horizontal parallax, or angle *O A L*, equal to the angle *A L C*, is very discernible, being 57′ 18″, or 3438″ at its mean state; which is more than 340 times as great as the Sun's: and, therefore, the distances of the heavenly bodies being inversely as the tangents of their horizontal parallaxes, the Sun's distance from the Earth is at least 340 times as great as the Moon's; and is rather under-rated at 81,000,000 of miles, when the Moon's distance is certainly known to be 240,000. But because, according to some astronomers, the Sun's horizontal parallax is 11″, and, according to others, only 10″, the former parallax making the Sun's distance to be about 75,000,000 of miles, and the latter 82,000,000; we may take it for granted, that the Sun's distance is not less, than as deduced from the former, nor more than as shewn by the latter: and every one who is accustomed to make such observations, knows how hard it is, if not impossible, to avoid an error of a second; especially on account of the inconstancy of horizontal refractions. And here, the error of one second, in so small an angle, will make an error of 7,000,000 of miles in so great a distance as that of the Sun's. But Dr. Halley has shewn us how the Sun's distance from the Earth, and, consequently, the distances of all the planets from the Sun, may be known to within a 500th part of the whole, by a transit of Venus over the Sun's disc, which will happen on the 6th of June, in the year 1761; till which time we must content ourselves with allowing the Sun's distance to be about 81,000,000 of miles, as commonly stated by astronomers.[3]

The Sun's distance cannot be yet so exactly determined as the Moon's.

How near the truth it may soon be determined.

192. The Sun and Moon appear much about the same bulk; and every one who understands geometry, knows how their true bulks may be deduced from the apparent, when their real distances are known. Spheres are to one another as the cubes of their diameters; whence, if the Sun be 81,000,000 of miles from the

The Sun proved to be much bigger than the Moon.

[3] From observations on the transit of Venus in 1761 and 1769, the horizontal parallax of the Sun was found to be nearly 8″.61 which gives us for the mean distance of the Sun from the Earth 95,000,000 of miles.—*Ed.*

Earth, to appear as big as the Moon, whose distance does not exceed 240,000 miles, he must, in solid bulk, be 42,875,000 times as big as the Moon.

193. The horizontal parallaxes are best observed at the equator: 1. Because the heat is so nearly equal every day, that the refractions are almost constantly the same: 2. Because the parallactic angle is greater there, as at *A* (the distance from thence to the Earth's axis being greater), than upon any parallel of latitude, as *a* or *b*.

The relative distances of the planets from the Sun are known to great precision, though their real distances are not well known.

194. The Earth's distance from the Sun being determined, the distances of all the other planets from him are easily found by the following analogy, their periods round him being ascertained by observation. As the square of the Earth's period round the Sun, is to the cube of its distance from the Sun, so is the square of the period of any other planet to the cube of its distance in such parts or measures as the Earth's distance was taken; see § 111. This proportion gives the relative mean distances of the planets from the Sun to the greatest degree of exactness; and they are as follows, having been deduced from their periodical times, according to the law just mentioned, which was discovered by Kepler, and demonstrated by Sir Isaac Newton[4].

195. These numbers shew, that although we have the rela-

[4] The following calculations, except those in the two last lines, were printed in former editions of this work, before the year 1761. Since that time, these two lines (as found by the transit A. D. 1761) were added; and also § 195.

PERIODICAL REVOLUTIONS TO THE SAME FIXED STAR IN DAYS AND DECIMAL PARTS OF A DAY.

Mercury	Venus	The Earth	Mars	Jupiter	Saturn
87.9692	224.6176	365.2564	686.9785	4332.514	10759.275
Relative mean distances from the Sun.					
38710	72333	100000	152369	520096	954006
From these numbers we deduce, that if the Sun's horizontal parallax be 10″, the real mean distances of the planets from the Sun in English miles are					
31,742,200	59,313,060	82,000,000	124,942,680	426,478,720	782,284,920
But if the Sun's parallax be 11″, their distances are no more than					
29,032,500	54,238,570	75,000,000	114,276,750	390,034,500	715,504,500
Errors in distance arising from the mistake of 1″ in the Sun's parallax.					
2,709,700	5,074,490	7,000,000	10,665,830	36,444,220	66,780,420
But, from the late transit of Venus A. D. 1761, the Sun's parallax appears to be only $8'' \frac{65}{100}$; and, according to that, their real distances in miles are					
36,841,468	68,891,486	95,173,127	145,014,148	494,990,976	907,956,130
And their diameters in miles are					
3100	9360	7970	5150	94,100	77,990

tive distances of the planets from the Sun to the greatest nicety, yet the best observers could not ascertain their true distances, until the late long-wished for transit appeared, which we must confess was embarrassed with several difficulties. But there will be another transit of Venus over the Sun on the 3d of June 1769, much better suited to this great problem. We wish the sky may be clear at all places of observation, since there will not be such an opportunity again in less than 105 years afterwards.

196. The Earth's axis produced to the stars, being carried[5] parallel to itself during the Earth's annual revolution, describes a circle in the sphere of the fixed stars equal to the orbit of the Earth. But this orbit, though very large, would seem no bigger than a point if it were viewed from the stars; and, consequently, the circle described in the sphere of the stars by the axis of the Earth produced, if viewed from the Earth, must appear but as a point, that is, its diameter appears too little to be measured by observation; for Dr. Bradley has assured us, that if it had amounted to a single second, or two at most, he should have perceived it in the great number of observations he has made, especially upon γ Draconis, and that it seemed to him very probable that the annual parallax of this star is not so great as a single second, and consequently that it is above 400,000 times farther from us than the Sun. Hence, the celestial poles seem to continue in the same points of the heavens throughout the year, which by no means disproves the Earth's annual motion, but plainly proves the distance of the stars to be exceeding great.

Why the celestial poles seem to keep still in the same points of the heavens, notwithstanding the Earth's motion round the Sun.

197. The small apparent motion of the stars, § 113, discovered by that great astronomer, he found to be nowise owing to their annual parallax (for it came out contrary thereto), but to the aberration of their light, which can result from no known cause besides that of the Earth's annual motion; and as it agrees so exactly therewith, it proves beyond dispute that the Earth has such a motion; for this aberration completes all its various phenomena every year, and proves that the velocity of star-light is such as carries it

The amazing velocity of light.

[5] By this is meant, that if a line be supposed to be drawn parallel to the Earth's axis in any part of its orbit, the axis keeps parallel to that line in every other part of its orbit; as in Fig. 1. of Plate V, where *a b c d e f g h* represents the Earth's orbit in an oblique view, and *Ns* the Earth's axis keeping always parallel to the line *MN*.

through a space equal to the Sun's distance from us in 8^m 13^s of time. Hence the velocity of light is (*Smith's Optics*, § 1197), 10,210 times as great as the Earth's velocity in its orbit; which velocity (from what we know already of the Earth's distance from the Sun) may be asserted to be at least between 57 and 58,000 miles every hour; and supposing it to be 58,000, this number multiplied by the 10,210, gives 592,180,000 miles for the hourly motion of light, which last number divided by 3600, the number of seconds in an hour, shews that light flies at the rate of more than 164,000 miles every second of time, or swing of a common clock pendulum. See § 166, note.

CHAP. X

THE CIRCLES OF THE GLOBE DESCRIBED—THE DIFFERENT LENGTHS OF DAYS AND NIGHTS, AND THE VICISSITUDES OF SEASONS EXPLAINED—THE EXPLANATION OF THE PHENOMENA OF SATURN'S RING CONCLUDED. (SEE § 81 AND 82.)

Circles of the sphere.

198. If the reader be hitherto unacquainted with the principal circles of the globe, he should now learn to know them, which he may do sufficiently for his present purpose in a quarter of an hour, if he sets the ball of a terrestrial globe before him, or looks at the figure of it, wherein these circles are drawn and named. The equator is that great circle which divides the northern half of the Earth from the southern. The tropics are lesser circles parallel to the equator, and each of them is $23\frac{1}{2}°$ from it, a degree in this sense being the 360th part of any great circle which divides the Earth into two equal parts. The tropic of Cancer lies on the north side of the equator, and the tropic of Capricorn on the south. The arctic circle has the north pole for its centre, and is just as far from the north pole as the tropics are from the equator; and the antarctic circle (hid by the supposed convexity of the figure) is just as far from the south pole every way round it. These poles are the very north and south points of the globe; and all other places are denominated northward or southward, according to the side of the equator they lie on,

Plate IV. Fig. 2.

Equator, tropics, polar circles, and poles.

and the pole to which they are nearest. The Earth's axis is a straight line passing through the centre of the Earth, perpendicular to the equator, and terminating in the poles at its surface. This, in the real Earth and planets, is only an imaginary line, but, in artificial globes or planets, it is a wire by which they are supported, and turned round in orreries, or such like machines, by wheel-work. The circles 12, 1, 2, 3, 4, &c. are meridians to all places they pass through; and we must suppose thousands more to be drawn, because every place that is ever so little to the east or west of any other place, has a different meridian from that other place. All the meridians meet in the poles, and whenever the Sun's centre is passing over any meridian in his apparent motion round the Earth, it is mid-day or noon to all places on that meridian.

Earth's axis.

Meridians.

199. The broad space lying between the tropics like a girdle surrounding the globe, is called the torrid zone, of which the equator is in the middle all around. The space between the tropic of Cancer and arctic circle is called the north temperate zone. That between the tropic of Capricorn and the antarctic circle, the south temperate zone. And the two circular spaces bounded by the polar circles are the two frigid zones, denominated north or south, from that pole which is in the centre of the one or the other of them.

Zones.

200. Having acquired this easy branch of knowledge, the learner may proceed to make the following experiment with his terrestrial ball, which will give him a plain idea of the diurnal and annual motions of the Earth, together with the different lengths of days and nights, and all the beautiful variety of seasons depending on those motions.

Take about seven feet of strong wire, and bend it into a circular form, as *abcd*, which being viewed obliquely, appears elliptical as in the figure. Place a lighted candle on a table, and having fixed one end of a silk thread *K* to the north pole of a small terrestrial globe *H*, about three inches diameter; cause another person to hold the wire circle, so that it may be parallel to the table, and as high as the flame of the candle *I*, which should be in or near the centre. Then, having twisted the thread as towards the left hand, that, by untwisting, it may turn the globe round eastward,

Plate IV, Fig. 3.

A pleasing experiment, shewing the different lengths of days and nights, and the variety of seasons.

or contrary to the way that the hands of a watch move; hang the globe by the thread within this circle, almost contiguous to it, and as the thread untwists, the globe (which is enlightened half round by the candle, as the Earth is by the Sun) will turn round its axis, and the different places upon it will be carried through the light and dark hemispheres, and have the appearance of a regular succession of days and nights, as our Earth has in reality by such a motion. As the globe turns, move your hands slowly, so as to carry the globe round the candle according to the order of the letters *abcd*, keeping its centre even with the wire circle; and you will perceive, that the candle being still perpendicular to the equator, will enlighten the globe from pole to pole in its whole motion round the circle, and that every place on the globe goes equally through the light and the dark, as it turns round by the untwisting of the thread, and therefore has a perpetual equinox or equality of day and night. The globe thus turning round represents the Earth turning round its axis; and the motion of the globe round the candle represents the Earth's annual motion round the Sun, and shews, that if the Earth's orbit had no inclination to its axis, all the days and nights of the year would be equally long, and there would be no different seasons. But now, desire the person who holds the wire to hold it obliquely in the position *ABCD*, raising the side ♋ just as much as he depresses the side ♑, that the flame may be still in the plane of the circle; and twisting the thread as before, that the globe may turn round its axis the same way as you carry it round the candle, that is, from West to East, let the globe down into the lowermost part of the wire circle at ♑, and if the circle be properly inclined,[1] the candle will shine perpendicularly on the tropic of Cancer, and the frigid zone, lying within the arctic or north polar circle, will be all in the light, as in the figure; and will keep in the light, let the globe turn round its axis ever so often. From the equator to the north polar circle, all the places have longer days and shorter nights; but from the equator to the south polar circle, just the reverse. The Sun does not set to any part of the north frigid zone, as shewn by the candle's shining on it, so that the motion of the

Summer solstice.

[1] At an angle of 23½° to the horizon, or to the plane of the table which supports the candle.—*Ed.*

globe can carry no place of that zone into the dark; and at the same time the south frigid zone is involved in darkness, and the turning of the globe brings none of its places into the light. If the Earth were to continue in the light part of its orbit, the Sun would never set to the inhabitants of the north frigid zone, nor rise to those of the south. At the equator it would be always equal day and night; and as places are gradually more and more distant from the equator towards the arctic circle, they would have longer days and shorter nights, whilst those on the south side of the equator would have their nights longer than their days. In this case there would be continual summer on the north side of the equator, and continual winter on the south side of it.

But as the globe turns round its axis, move your hand slowly forward, so as to carry the globe from *H* towards *E*, and the boundary of light and darkness will approach towards the north pole, and recede towards the south pole; the northern places will go through less and less of the light, and the southern places through more and more of it, shewing how the northern days decrease in length, and the southern days increase, whilst the globe proceeds from *H* to *E*. When the globe is at *E*, it is at a mean state between the lowest and highest parts of its orbit; the candle is directly over the equator, the boundary of light and darkness just reaches to both the poles, and all places on the globe go equally through the light and dark hemispheres, shewing that the days and nights are then equal at all places of the Earth, the poles only excepted, for the Sun is then setting to the north pole, and rising to the south pole. Autumnal equinox.

Continue moving the globe forward, and as it goes through the quarter *A*, the north pole recedes still farther into the dark hemisphere, and the south pole advances more into the light, as the globe comes nearer to ♑; and when it comes there at *F*, the candle is directly over the tropic of Capricorn, the days are at the shortest, and nights at the longest, in the northern hemisphere, all the way from the equator to the arctic circle, and the reverse in the southern hemisphere from the equator to the antarctic circles; within which circle it is dark to the north frigid zone, and light to the south. Winter solstice.

Continue both motions, and as the globe moves through the quarter *B*, the north pole advances towards the light, and the

south pole recedes towards the dark; the days lengthen in the northern hemisphere, and shorten in the southern; and when the globe comes to *G*, the candle will be again over the equator (as when the globe was at *E*), and the days and nights will again be equal as formerly, and the north pole will be just coming into the light as the south pole is going out of it.

Vernal equinox.

Thus we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is sometimes no day or night for many turnings of the Earth, within the polar circles; why there is but one day and one night in the whole year at the poles; and why the days and nights are equally long all the year round at the equator, which is always equally cut by the circle bounding light and darkness.

Remark.

201. The inclination of an axis or orbit is merely relative, because we compare it with some other axis or orbit which we consider as not inclined at all. Thus, our horizon being level to us, whatever place of the Earth we are upon, we consider it as having no inclination; and yet, if we travel 90° from that place, we shall then have an horizon perpendicular to the former, but it will still be level to us. And if Plate IV be held so that the circle[2] *ABCD* be parallel to the horizon, both the circle *abcd*, and the thread or axis *K*, will be inclined to it. But if the plate be held so that the thread be perpendicular to the horizon, then the orbit *ABCD* will be inclined to the thread, and the orbit *abcd* perpendicular to it, and parallel to the horizon. We generally consider the Earth's annual orbit, as having no inclination, and the orbits of all the other planets as inclined to it, § 20.

Fig. 3.

202. Let us now take a view of the Earth, in its annual course round the Sun, considering its orbit as having no inclination; and its axis as inclining $23\frac{1}{2}$° from a line perpendicular to the plane of its orbit, and keeping the same oblique direction in all parts of its annual course, or, as commonly termed, keeping always parallel to itself, § 196.

[2] All circles appear elliptical in an oblique view, as is evident by looking obliquely at the rim of a basin; for the true figure of a circle can only be seen when the eye is directly over its centre. The more obliquely it is viewed, the more elliptical it appears, until the eye be in the same plane with it, and then it appears like a straight line.

Let *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*; be the Earth in eight different parts of its orbit, equidistant from one another; *N s* its axis, *N* its north pole, *s* its south pole, and *S* the Sun nearly in the centre of the Earth's orbit, § 18. As the Earth goes round the Sun according to the order of the letters *abcd*, &c. its axis *Ns* keeps the same obliquity, and is still parallel to the line *MNs*. When the Earth is at *a*, its north pole inclines towards the Sun *S*, and brings all the northern places more into the light than at any other time of the year. But when the Earth is at *e* in the opposite time of the year, the north pole declines from the Sun, which occasions the northern places to be more in the dark than in the light; and the reverse at the southern places, as is evident by the figure which I have taken from Dr. Long's astronomy. When the Earth is either at *c* or *g*, its axis inclines neither to nor from the Sun, but lies sidewise to him; and then the poles are in the boundary of light and darkness, and the Sun, being directly over the equator, makes equal day and night at all places. When the Earth is at *b*, it is half-way between the summer solstice and harvest equinox; when it is at *d*, it is half-way from the harvest equinox to the winter solstice; at *f*, half-way from the winter solstice to the spring equinox; and at *h*, half-way from the spring equinox to the summer solstice.

Plate V, Fig. 1.

A concise view of the seasons.

203. From this oblique view of the Earth's orbit, let us suppose ourselves to be raised far above it, and placed just over its centre *S*, looking down upon it from its north pole; and as the Earth's orbit differs but very little from a circle, we shall have its figure in such a view represented by the circle *ABCDEFGH*. Let us suppose this circle to be divided into 12 equal parts, called signs, having their names affixed to them; and each sign into 30 equal parts, called degrees, numbered 10, 20, 30, as in the outermost circle of the figure, which represents the great ecliptic in the heavens. The Earth is shewn in eight different positions in this circle, and in each position *Æ* is the equator, *T* the tropic of Cancer, the dotted circle the parallel of London, *U* the arctic or north polar circle, and *P* the north pole, where all the meridians or hour-circles meet, § 198. As the Earth goes round the Sun, the north pole keeps

Fig. 2.

The seasons shewn in another view of the Earth and its orbit.

constantly towards one part of the heavens, as it keeps in the figure towards the right hand side of the plate.

Vernal equinox.

When the Earth is at the beginning of Libra, namely, on the 20th of March, in this figure (as at *g* in Fig. 1) the Sun *S* as seen from the Earth appears at the beginning of Aries in the opposite part of the heavens,[3] the north pole is just coming into the light, and the Sun is vertical to the equator; which, together with the tropic of Cancer, parallel of London, and arctic circle, are all equally cut by the circle bounding light and darkness, coinciding with the six o'clock hour circle, and therefore the days and nights are equally long at all places; for every part of the meridian *ÆTLa* comes into the light at six in the morning, and revolving with the Earth according to the order of the hour-letters, goes into the dark at six in the evening. There are 24 meridians or hour-circles drawn on the Earth in this figure, to shew the time of Sun rising and setting at different seasons of the year.

As the Earth moves in the ecliptic according to the order of the letters *ABCD*, &c. through the signs Libra, Scorpio, and Sagittarius, the north pole *P* comes more and more into the light; the days increase as the nights decrease in length, at all places north of the equator *Æ*, which is plain by viewing the Earth at *b* on the 5th of May, when it is in the 15th degree of Scorpio,[4] and the Sun as seen from the Earth appears in the 15th degree of Taurus.' For then, the tropic of Cancer *T* is in the light from a little after five in the morning till almost seven in the evening; the parallel of London from half an hour past four till half an hour past seven; the polar circle *U* from three till nine: and a large tract round the north pole *P* has day all the 24 hours, for many rotations of the Earth on its axis.

When the Earth comes to *c*, at the beginning of Capricorn, and the Sun as seen from the Earth appears at the beginning of Cancer, on the 21st of June, as in this figure, it is in the position *a* in Fig. 1; and its north pole inclines towards the Sun, so as to bring all the north frigid zone into the light, and the northern parallels of latitude more into the light than the dark.

[3] Here we must suppose the Sun to be no bigger than an ordinary point (as.) because he only covers a circle half a degree in diameter in the heavens; whereas in the figure he hides a whole sign at once from the Earth.

[4] Here we must suppose the Earth to be a much smaller point than that in the preceding note marked for the Sun.

from the equator to the polar circle, and the more so as they are farther from the equator. The tropic of Cancer is in the light from five in the morning till seven at night, the parallel of London from a quarter before four till a quarter after eight; and the polar circle just touches the dark, so that the Sun has only the lower half of his disc hid from the inhabitants on that circle for a few minutes about midnight, supposing no inequalities in the horizon, and no refractions. Summer solstice.

A bare view of the figure is enough to shew, that as the Earth advances from Capricorn towards Aries, and the Sun appears to move from Cancer towards Libra, the north pole recedes towards the dark, which causes the days to decrease, and the nights to increase in length, till the Earth comes to the beginning of Aries, and then they are equal as before, for the boundary of light and darkness cuts the equator and all its parallels equally, or in halves. The north pole then goes into the dark, and continues therein until the Earth goes half way round its orbit, or from the 23d of September till the 20th of March. In the middle between these times, viz. on the 22d of December, the north pole is as far as it can be in the dark, which is 23½, equal to the inclination of the Earth's axis from a perpendicular to its orbit, and then the northern parallels are as much in the dark as they were in the light on the 21st of June; the winter nights being as long as the summer days, and the winter days as short as the summer nights. It is needless to enlarge farther on this subject, as we shall have occasion to mention the seasons again in describing the Orrery, § 439. Only this must be noted, that all that has been said of the northern hemisphere, the contrary must be understood of the southern; for, on different sides of the equator the seasons are contrary, because, when the northern hemisphere inclines towards the Sun, the southern declines from him. Autumnal equinox. Winter solstice.

204. As Saturn goes round the Sun, his obliquely posited ring, like our Earth's axis, keeps parallel to itself, and is therefore turned edgewise to the Sun twice in a Saturnian year, which is almost as long as 30 of our years, § 81. But the ring, though considerably broad, is too thin to be seen by us when it is turned edgewise to the Sun, at which time it is also edgewise to the Earth; and therefore it The phenomena of Saturn's ring.

disappears once in every 15 years to us. As the Sun shines half a year together on the north pole of our Earth, then disappears to it, and shines as long on the south pole; so, during one half of Saturn's year, the Sun shines on the north side of his ring, then disappears to it, and shines as long on its south side. When the Earth's axis inclines neither to nor from the Sun, but sidewise to him, he instantly ceases to shine on one pole, and begins to enlighten the other; and when Saturn's ring inclines neither to nor from the Sun, but sidewise to him, he ceases to shine on the one side of it, and begins to shine upon the other.

Appearance and disappearance of Saturn's ring.

Plate V. Fig. 3. Let *S* be the Sun, *ABCDEFGH* Saturn's orbit, and *IKLMNO* the Earth's orbit. Both Saturn and the Earth move according to the order of the letters, and when Saturn is at *A* his ring is turned edgewise to the Sun *S*, and he is then seen from the Earth as if he had lost his ring, let the Earth be in any part of its orbit whatever, except between *N* and *O*; for whilst it describes that space, Saturn is apparently so near the Sun as to be hid in his beams. As Saturn goes from *A* to *C*, his ring appears more and more open to the Earth: at *C* the ring appears most open of all; and seems to grow narrower and narrower as Saturn goes from *C* to *E*; and when he comes to *E*, the ring is again turned edgewise both to the Sun and Earth; and as neither of its sides are illuminated, it is invisible to us, because its edge is too thin to be perceptible, and Saturn appears again as if he had lost his ring. But as he goes from *E* to *G*, his ring opens more and more to our view on the under side, and seems just as open at *G* as it was at *C*, and may be seen in the night-time from the Earth in any part of its orbit, except about *M*, when the Sun hides the planet from our view. As Saturn goes from *G* to *A*, his ring turns more and more edgewise to us, and therefore it seems to grow narrower and narrower, and at *A* it disappears as before. Hence, while Saturn goes from *A* to *E*, the Sun shines on the upper side of his ring, and the under side is dark; and whilst he goes from *E* to *A*, the Sun shines on the under side of his ring, and the upper side is dark.

It may perhaps be imagined, that this article might have been placed more properly after § 81 than here; but when Fig. 1 and 3. the candid reader considers, that all the various phenomena of Saturn's ring depend upon a cause similar

to that of our Earth's seasons, he will readily allow that they are best explained together, and that the two figures serve to illustrate each other.

205. The Earth's orbit being elliptical, and the Sun constantly keeping in its lower focus, which is 1,377,000 miles from the middle point of the longer axis, the Earth comes twice so much, or 2,754,000 miles nearer the Sun at one time of the year than at another; for the Sun appearing under a larger angle in our winter than summer, proves that the Earth is nearer the Sun in winter (see the note on article 185). But here this natural question will arise, Why have we not the hottest weather when the Earth is nearest the Sun? In answer, it must be observed, that the eccentricity of the Earth's orbit, or 1,377,000 miles, bears no greater proportion to the Earth's mean distance from the Sun than 17 does to 1000; and therefore this small difference of distance cannot occasion any great difference of heat or cold. But the principal cause of this difference is, that in winter the Sun's rays fall so obliquely upon us, that any given number of them is spread over a much greater portion of the Earth's surface where we live, and therefore each point must then have fewer rays than in summer. Moreover, there comes a greater degree of cold in the long winter nights than there can return of heat in so short days, and on both these accounts the cold must increase. But in summer the Sun's rays fall more perpendicularly upon us, and therefore come with greater force, and in greater numbers on the same place, and, by their long continuance, a much greater degree of heat is imparted by day than can fly off by night.

The Earth nearer the Sun in winter than in summer.

Why the weather is coldest when the Earth is nearest the Sun.

206. That a greater number of rays fall on the same place, when they come perpendicularly, than when they come obliquely on it, will appear by the figure. (See § 169, note.) For, let *AB* be a certain number of the Sun's rays falling on *CD* (which let us suppose to be London) on the 21st of June; but, on the 22d of December, the line *CD*, or London, has the oblique position *Cd* to the same rays, and therefore scarce a third part of them falls upon it, or only those between *A* and *c*, all the rest *cB* being expended on the space *dP*, which is more than double the length of *CD* or *Cd*. Besides, those parts which are once heated, retain the heat for

Plate VI. Fig. 2.

some time, which, with the additional heat daily imparted, makes it continue to increase, though the Sun declines towards the south, and this is the reason why July is hotter than June, although the Sun has withdrawn from the summer tropic, as we find it is generally hotter at three in the afternoon, when the Sun has gone towards the west, than at noon, when he is on the meridian. Likewise, those places which are well cooled require time to be heated again, for the Sun's rays do not heat even the surface of any body till they have been some time upon it. And therefore we find January for the most part colder than December, although the Sun has withdrawn from the winter tropic, and begins to dart his beams more perpendicularly upon us, when we have the position CF. An iron bar is not heated immediately upon being put into the fire, nor grows cold till some time after it has been taken out.

CHAP. XI.

THE METHOD OF FINDING THE LONGITUDE BY THE ECLIPSES OF JUPITER'S SATELLITES.—THE AMAZING VELOCITY OF LIGHT DEMONSTRATED BY THESE ECLIPSES.

First meridian and longitude of places, what.

207. GEOGRAPHERS arbitrarily choose to call the meridian of some remarkable place the first meridian. There they begin their reckoning, and just so many degrees and minutes as any other place is to the eastward or westward of that meridian, so much east or west longitude they say it has. A degree is the 360th part of a circle, be it great or small, and a minute the 60th part of a degree. The English geographers reckon the longitude from the meridian of the royal observatory at Greenwich, and the French from the meridian of Paris.

Plate V. Fig. 2.

208. If we imagine 12 great circles, one of which is the meridian of any given place, to intersect each other in the two poles of the Earth, and to cut the equator $Æ$ at every 15th degree, they will be divided by the poles into 24 semicircles, which divide the equator into 24 equal parts; and as the Earth turns on its axis, the planes of these semicircles

come successively after one another every hour to the Sun. As in an hour of time there is a revolution of 15° of the equator, in a minute of time there will be a revolution of 15′ of the equator, and in a second of time a revolution of 15″. There are two tables annexed to this chapter for reducing mean solar time into degrees and minutes of the terrestrial equator, and also for converting degrees and parts of the equator into mean solar time.

Hour-circles. An hour of time equal to 15° of motion.

209. Because the Sun enlightens only one-half of the Earth at once, as it turns round its axis, he rises to some places at the same moments of absolute time when he sets to others; and when it is mid-day to some places, it is mid-night to others. The XII on the middle of the Earth's enlightened side next the Sun stands for mid-day, and the opposite XII on the middle of the dark side for midnight. If we suppose this circle of hours to be fixed in the plane of the equinoctial, and the Earth to turn round within it, any particular meridian will come to the different hours, so as to shew the true time of the day or night at all places on that meridian. Therefore,

210. To every place 15° eastward from any given meridian, it is noon an hour sooner than on that meridian; because their meridian comes to the Sun an hour sooner; and, to all places 15° westward, it is noon an hour later, § 208, because their meridian comes an hour later to the Sun, and so on; every 15° of motion causing an hour's difference of time. Therefore, they who have noon an hour later than we, have their meridian, that is, their longitude, 15° westward from us; and they who have noon an hour sooner than we, have their meridian 15° eastward from ours, and so for every hour's difference of time 15° difference of longitude. Consequently, if the beginning or ending of a lunar eclipse be observed, suppose at London, to be exactly at mid-night, and in some other place at 11 at night, that place is 15° westward from the meridian of London: if the same eclipse be observed at 1 in the morning at another place, that place is 15° eastward from the said meridian.[1]

And consequently to 15° of longitude.

Lunar eclipses useful in finding the longitude.

[1] The longitude may be determined also, by observing the arrival of the Earth's shadow at the different spots on the Moon's surface. This method now obtains universally among astronomers, and is pretty accurate, as we can take the medium of

211. But as it is not easy to determine the exact moment either of the beginning or ending of a lunar eclipse, because the Earth's shadow through which the Moon passes, is faint and ill defined about the edges, we have recourse to the eclipses of Jupiter's satellites, which disappear so instantaneously as they enter into Jupiter's shadow, and emerge so suddenly out of it, that we may fix the phenomenon to a second of time. The first, or nearest satellite to Jupiter, is the most advantageous for this purpose, because its motion is quicker than the motion of any of the rest, and therefore its immersions and emersions are more frequent.

Eclipses of Jupiter's satellites much better for that purpose.

212. The English astronomers have calculated tables for shewing the times of the eclipses of Jupiter's satellites to great precision, for the meridian of Greenwich.[2] Now, let an observer, who has these tables, with a good telescope, and a well regulated clock, at any other place of the Earth, observe the beginning or ending of an eclipse of one of Jupiter's satellites, and note the precise moment of time that he saw the satellite either immerge into, or emerge out of the shadow, and compare that time with the time shewn by the tables for Greenwich; then, 15° difference of longitude being allowed for every hour's difference of time, will give the longitude of that place from Greenwich, as above, § 210; and if there be any odd minutes of time, for every minute a quarter of a degree, east or west, must be allowed, as the time of observation is later or earlier than the time shewn by the tables. Such eclipses are very convenient for this purpose at land, because they happen almost every day; but are of no use at sea, because the rolling of the ship hinders all nice telescopical observations.

How to solve this important problem.

Plate V. Fig. 2.

213. To explain this by a figure, let *J* be Jupiter, *K*, *L*, *M*, *N*, his four satellites in their respective

a great number of observations. It is necessary, however, to be acquainted with the names and position of the lunar spots. See the Supplementary chapter on *Selenography*.—*Ed.*

[2] The eclipses of all Jupiter's satellites are inserted in the Nautical Almanack every year, and are computed from the accurate tables of Delambre. The eclipses of the first and second satellites are most proper for finding the longitude, not only because their theory is much more perfect than that of the other two; but because it is difficult to observe the exact time when the third and fourth satellites enter into, and emerge from, the shadow of Jupiter.—*Ed.*

orbits 1, 2, 3, 4; and let the Earth be at *f* (suppose in November, although that month is no otherwise material than to find the Earth readily in this scheme, where it is shewn in eight different parts of its orbit). Let *Q* be a place on the meridian of Greenwich, and *R* a place on some other meridian eastward from Greenwich. Let a person at *R* observe the instantaneous vanishing of the first satellite *K* into Jupiter's shadow, suppose at 3 o'clock in the morning; but by the tables he finds the immersion of that satellite to be at midnight at Greenwich: he can then immediately determine, that as there are 3 hours difference of time between *Q* and *R*, and that *R* is 3 hours forwarder in reckoning than *Q*, it must be 45° of east longitude from the meridian of *Q*. Were this method as practicable at sea as at land, any sailor might almost as easily, and with equal certainty, find the longitude as the latitude.

Illustrated by an example.

214. Whilst the Earth is going from *C* to *F* in its orbit, only the immersions of Jupiter's satellites into his shadow are generally seen; and their emersions out of it while the Earth goes from *G* to *B*. Indeed, both these appearances may be seen of the 2d, 3d, and 4th, satellite when eclipsed, whilst the Earth is between *D* and *E*, or between *G* and *A*; but never of the 1st satellite, on account of the smallness of its orbit and the bulk of Jupiter; except only when Jupiter is directly opposite to the Sun; that is, when the Earth is at *g*: and even then, strictly speaking, we cannot see either the immersions or emersions of any of his satellites, because his body being directly between us and his conical shadow, his satellites are hid by his body a few moments before they touch his shadow; and are quite emerged from thence before we can see them, as it were, just dropping from him. And when the Earth is at *c*, the Sun, being between it and Jupiter, hides both him and his moons from us.

We seldom see the beginning and end of the same eclipse of any of Jupiter's moons.

In this diagram, the orbits of Jupiter's moons are drawn in true proportion to his diameter; but, in proportion to the Earth's orbit, they are drawn 81 times too large.

215. In whatever month of the year Jupiter is in conjunction with the Sun, or in opposition to him, in the next year it will be a month later at least. For, whilst the Earth goes

Jupiter's conjunctions with the Sun, or oppositions to him, are every year in different parts of the heavens.

once round the Sun, Jupiter describes a 12th part of his orbit. And, therefore, when the Earth has finished its annual period from being in a line with the Sun and Jupiter, it must go as much forwarder as Jupiter has moved in that time, to overtake him again: just like the minute-hand of a watch, which must, from any conjunction with the hour-hand, go once round the dial-plate, and somewhat above a 12th part more, to overtake the hour-hand again.

216. It is found by observation, that when the Earth is between the Sun and Jupiter, as at *g*, his satellites are eclipsed about 8 minutes sooner than they should be according to the tables: and when the Earth is at *B* or *C*, these eclipses happen about 8 minutes later than the tables predict them. Hence it is undeniably certain that the motion of light is not instantaneous, since it takes about 16½ minutes of time to go through a space equal to the diameter of the Earth's orbit, which is 162,000,000 of miles in length: and, consequently, the particles of light fly about 164,494 miles every second of time, which is above 1,000,000 of times swifter than the motion of a cannon bullet. And as light takes 16½ minutes to travel across the Earth's orbit, it must be 8¼ minutes in coming from the Sun to us; therefore, if the Sun were annihilated, we should see him for 8¼ minutes after: and if he were again created, he would be 8¼ minutes old before we could see him.

The surprising velocity of light.

Plate VI. Fig. 5.

217. To explain the progressive motion of light, let *A* and *B* be the Earth in two different parts of its orbit, whose distance from each other is 81,000,000 of miles, equal to the Earth's distance from the Sun *S*: it is plain, that if the motion of light were instantaneous, the satellite 1 would appear to enter into Jupiter's shadow *FF* at the same moment of time to a spectator in *A* as to another in *B*. But by many years' observation it has been found, that the immersion of the satellite into the shadow, is seen 8¼ minutes sooner when the Earth is at *B*, than when it is at *A*. And so, as Mr. Romer first discovered, the motion of light is thereby proved to be progressive, and not instantaneous, as was formerly believed. It is easy to compute in what time the Earth moves from *A* to *B*; for the chord of 60° of any circle

Illustrated by a figure.

is equal to the semi-diameter of that circle; and as the Earth goes through all the 360° of its orbit in a year, it goes through 60 of those degrees in about 61 days. Therefore, if on any given day, suppose the 1st of June, the Earth is at *A*, on the 1st of August it will be at *B*: the chord, or straight line *A B*, being equal to *D S*, the radius of the Earth's orbit, the same with *A S* its distance from the Sun.

218. As the Earth moves from *D* to *C*, through the side *A B* of its orbit, it is constantly meeting the light of Jupiter's satellites sooner, which occasions an apparent acceleration of their eclipses: and as it moves through the other half *H* of its orbit, from *C* to *D*, it is receding from their light, which occasions an apparent retardation of their eclipses, because their light is then longer before it overtakes the Earth.

219. That these accelerations of the immersions of Jupiter's satellites into his shadow, as the Earth approaches towards Jupiter, and the retardations of their immersions out of his shadow, as the Earth is going from him, are not occasioned by any inequality arising from the motions of the satellites in eccentric orbits, is plain, because it affects them all alike, in whatever parts of their orbits they are eclipsed. Besides, they go often round their orbits every year, and their motions are no way commensurate to the Earth's. Therefore, a phenomenon not to be accounted for from the real motions of the satellites, but so easily deducible from the Earth's motion, and so answerable thereto, must be allowed to result from it. This affords one very good proof of the Earth's annual motion.

220. *Tables for converting mean solar Time into Degrees and Parts of the Terrestrial Equator; and also for converting Degrees and Parts of the Equator into mean solar Time.*

TABLE I. For converting Time into Degrees and Parts of the Equator.

Hours.	Degrees.	Min. / Sec. / Thirds.	Deg. / Min. / Sec.	Min. / Sec. / Thirds.	Min. / Sec. / Thirds.	Deg. / Min. / Sec.	Min. / Sec. / Thirds.
1	15	1	0	15	31	7	45
2	30	2	0	30	32	8	0
3	45	3	0	45	33	8	15
4	60	4	1	0	34	8	30
5	75	5	1	15	35	8	45
6	90	6	1	30	36	9	0
7	105	7	1	45	37	9	15
8	120	8	2	0	38	9	30
9	135	9	2	15	39	9	45
10	150	10	2	30	40	10	0
11	165	11	2	45	41	10	15
12	180	12	3	0	42	10	30
13	195	13	3	15	43	10	45
14	210	14	3	30	44	11	0
15	225	15	3	45	45	11	15
16	240	16	4	0	46	11	30
17	255	17	4	15	47	11	45
18	270	18	4	30	48	12	0
19	285	19	4	45	49	12	15
20	300	20	5	0	50	12	30
21	315	21	5	15	51	12	45
22	330	22	5	30	52	13	0
23	345	23	5	45	53	13	15
24	360	24	6	0	54	13	30
25	375	25	6	15	55	13	45
26	390	26	6	30	56	14	0
27	405	27	6	45	57	14	15
28	420	28	7	0	58	14	30
29	435	29	7	15	59	14	45
30	450	30	7	30	60	15	0

TABLE II. For converting Degrees and Parts of the Equator into Time.

Deg. / Min. / Sec.	Hours / Min. / Sec.	Min. / Sec. / Thirds.	Deg. / Min. / Sec.	Hours / Min. / Sec.	Min. / Sec. / Thirds.	Degrees.	Hours.	Minutes.
1	0	4	31	2	4	70	4	40
2	0	8	32	2	8	80	5	20
3	0	12	33	2	12	90	6	0
4	0	16	34	2	16	100	6	40
5	0	20	35	2	20	110	7	20
6	0	24	36	2	24	120	8	0
7	0	28	37	2	28	130	8	40
8	0	32	38	2	32	140	9	20
9	0	36	39	2	36	150	10	0
10	0	40	40	2	40	160	10	40
11	0	44	41	2	44	170	11	20
12	0	48	42	2	48	180	12	0
13	0	52	43	2	52	190	12	40
14	0	56	44	2	56	200	13	20
15	1	0	45	3	0	210	14	0
16	1	4	46	3	4	220	14	40
17	1	8	47	3	8	230	15	20
18	1	12	48	3	12	240	16	0
19	1	16	49	3	16	250	16	40
20	1	20	50	3	20	260	17	20
21	1	24	51	3	24	270	18	0
22	1	28	52	3	28	280	18	40
23	1	32	53	3	32	290	19	20
24	1	36	54	3	36	300	20	0
25	1	40	55	3	40	310	20	40
26	1	44	56	3	44	320	21	20
27	1	48	57	3	48	330	22	0
28	1	52	58	3	52	340	22	40
29	1	56	59	3	56	350	23	20
30	2	0	60	4	0	360	24	0

These are the tables mentioned in the 208th article, and are so easy that they scarce require any farther explanation than to inform the reader, that if, in Table I, he reckons the columns marked with asterisks to be minutes of time, the other columns give the equatorial parts or motion in degrees and minutes; if he reckons the asterisk columns to be seconds, the others give the motion in minutes and seconds of the equator; if thirds, in seconds and thirds; and if, in Table II, he reckons the asterisk columns to be degrees of motion, the others give the time answering thereto in hours and minutes; if minutes of motion, the time in minutes and seconds; if seconds of motion, the corresponding time is given in seconds and thirds. An example in each case will make the whole very plain.

EXAMPLE I.

In 10^h 15^m 24^s 20th, *Qu.* How much of the equator revolves through the meridian?

		D.	M.	S.
Hours	10	150	0	0
Min	15	3	45	0
Sec.	24		6	0
Thirds	20			5
Answer		153	51	5

EXAMPLE II.

In what time will 153° 51′ 5″ of the equator revolve through the meridian?

			H.	M.	S.	T.
Deg.		150	10	0	0	0
		3		12	0	0
Min.		51			3	24	0
Sec.		5				20
Answer			10	15	24	20

CHAP. XII.

OF SOLAR AND SYDEREAL TIME.

Sydereal days shorter than solar days, and why.

221. THE stars appear to go round the Earth in 23^h 56^m 4^s, and the Sun in 24^h: so that the stars gain 3^m 56^s upon the Sun every day, which amounts to one diurnal revolution in a year; and, therefore, in 365^d, as measured by the returns of the Sun to the meridian, there are 366^d, as measured by the stars returning to it: the former are called *solar days*, and the latter *sydereal*.

The diameter of the Earth's orbit is but a physical point in proportion to the distance of the stars; for which reason, and the Earth's uniform motion on its axis, any given meridian will

revolve from any star to the same star again in every absolute turn of the Earth on its axis, without the least perceptible difference of time shewn by a clock which goes exactly true.

If the Earth had only a diurnal, without an annual motion, any given meridian would revolve from the Sun to the Sun again in the same quantity of time, as from any star to the same star again; because the Sun would never change his place with respect to the stars. But, as the Earth advances almost a degree eastward in its orbit in the time that it turns eastward round its axis, whatever star passes over the meridian on any day with the Sun, will pass over the same meridian on the next day, when the Sun is almost a degree short of it; that is, 3′ 56″ sooner. If the year contained only 360 days, as the ecliptic does 360 degrees, the Sun's apparent place, so far as his motion is equable, would change a degree every day; and then the sydereal days would be just 4 minutes shorter than the solar.

Plate III. Fig. 2. Let *ABCDEFGHIKLM* be the Earth's orbit, in which it goes round the Sun every year, according to the order of the letters, that is, from west to east; and turns round its axis the same way from the Sun to the Sun again in every 24 hours. Let *S* be the Sun and *R* a fixed star, at such an immense distance, that the diameter of the Earth's orbit bears no sensible proportion to that distance. Let *N m* be any particular meridian of the Earth, and *N* a given point or place upon that meridian. When the Earth is at *A*, the Sun *S* hides the star *R*, which would be always hid if the Earth never removed from *A*; and, consequently, as the Earth turns round its axis, the point *N* would always come round to the Sun and star at the same time. But when the Earth has advanced, suppose a 12th part of its orbit from *A* to *B*, its motion round its axis will bring the point *N* a 12th part of a natural day, or 2 hours, sooner to the star than to the Sun; for the angle *N B n* is equal to the angle *A S B*; and, therefore, any star which comes to the meridian at noon with the Sun when the Earth is at *A*, will come to the meridian at 10 in the forenoon, when the Earth is at *B*. When the Earth comes to *C*, the point *N* will have the star on its meridian at 8 in the morning, or 4 hours sooner than it comes round to the Sun: for it must revolve from *N* to *n*, before it has the Sun in its meridian. When the Earth comes to *D*, the point *N* will have the star on its meridian at 6 in the morning, but that point must revolve 6 hours more from *N* to

n, before it has mid-day by the Sun: for now the angle *A S D* is a right angle, and so is *N D n*; that is, the Earth has advanced 90° in its orbit, and must turn 90° on its axis to carry the point *N* from the star to the Sun: for the star always comes to the meridian when *N m* is parallel to *R S A*; because *D S* is but a point in respect of *R S*. When the Earth is at *E*, the star comes to the meridian at 4 in the morning; at *F*, at 2 in the morning; and at *G*, the Earth having gone half round its orbit, *N* points to the star *R* at midnight, it being then directly opposite to the Sun; and, therefore, by the Earth's diurnal motion, the star comes to the meridian 12 hours before the Sun. When the Earth is at *H*, the star comes to the meridian at 10 in the evening; at *I* it comes to the meridian at 8, that is, 16 hours before the Sun; at *K* 18 hours before him; at *L* 20 hours; at *M* 22 hours; and at *A* equally with the Sun again.

A Table, shewing how much of the Celestial Equator passes over the Meridian in any part of a mean Solar Day, and how much the Fixed Stars gain upon the mean Solar Time every Day, for a Month.*

Time.	Motion.			Time.	Motion.			Time.	Motion.			Acceleration of the Fixed Stars			
				*Min	Deg	Min	Sec	*Min	Deg	Min	Sec				
				Sec.	Min	Sec	Th	Sec.	Min	Sec	Th				
Hours	Deg.	Min	Sec	Th.	Sec.	Th		Th	Sec	Th		D	H	M	S
1	15	2	28	1	0	15	2	31	7	46	16	1	0	3	56
2	30	4	56	2	0	30	5	32	8	1	19	2	0	7	52
3	45	7	24	3	0	45	7	33	8	16	2	3	0	11	48
4	60	9	51	4	1	0	10	34	8	31	24	4	0	15	44
5	75	12	19	5	1	15	12	35	8	46	26	5	0	19	39
6	90	14	47	6	1	30	15	36	9	1	29	6	0	23	35
7	105	17	15	7	1	45	17	37	9	16	31	7	0	27	31
8	120	19	43	8	2	0	20	38	9	31	34	8	0	31	27
9	135	22	11	9	2	15	22	39	9	46	36	9	0	35	23
10	150	24	38	10	2	30	25	40	10	1	39	10	0	39	19
11	165	27	6	11	2	45	27	41	10	16	41	11	0	43	15
12	180	29	34	12	3	0	30	42	10	31	43	12	0	47	11
13	195	32	2	13	3	15	32	43	10	46	46	13	0	51	7
14	210	34	30	14	3	30	34	44	11	1	48	14	0	55	3
15	225	36	58	15	3	45	37	45	11	16	51	15	0	58	58
16	240	39	26	16	4	0	39	46	11	31	53	16	1	2	54
17	255	41	53	17	4	15	41	47	11	16	56	17	1	6	50
18	270	44	21	18	4	30	44	48	12	1	58	18	1	10	46
19	285	46	49	19	4	45	47	49	12	17	1	19	1	14	42
20	300	49	17	20	5	0	49	50	12	32	3	20	1	18	38
21	315	51	45	21	5	15	52	51	12	47	6	21	1	22	34
22	330	54	13	22	5	30	54	52	13	2	8	22	1	26	30
23	345	50	40	23	5	45	57	53	13	17	11	23	1	30	26
24	360	59	8	24	6	0	59	54	13	32	13	24	1	34	12
25	376	1	36	25	6	16	2	55	13	47	16	25	1	38	17
26	391	4	4	26	6	31	4	56	14	2	18	26	1	42	13
27	406	6	32	27	6	46	7	57	14	17	21	27	1	46	9
28	421	9	0	28	7	1	9	58	14	32	23	28	1	50	5
29	436	11	28	29	7	16	11	59	14	47	26	29	1	54	1
30	451	13	50	30	7	31	14	60	15	2	28	30	1	57	57

222. Thus it is plain, that an absolute turn of the Earth on its axis (which is always completed when any particular meridian comes to be parallel to its situation at any time of the day before) never brings the same meridian round from the Sun to the Sun again; but that the Earth requires as much more than one turn on its axis to finish a natural day, as it has gone forward in that time; which, at a mean state, is a 365th part of a circle Hence, in 365 days, the Earth turns 366 times round its axis, and, therefore, as a turn of the Earth on its axis completes a sydereal day, there must be one sydereal day more in a year than the number of solar days, be the number what it will, on the Earth, or any other planet;—one turn being lost with respect to the number of solar days in a year, by the planet's going round the Sun, just as it would be lost to a traveller, who, in going round the Earth, would lose one day by following the apparent diurnal motion of the Sun; and, consequently, would reckon one day less at his return (let him take what time he would to go round the Earth) than those who remained all the while at the place from which he set out So, if there were two earths revolving equally on their axes, and if one remained at *A* until the other had gone round the Sun from *A* to *A* again, *that* earth which kept its place at *A* would have its solar and sydereal days always of the same length; and so would have one solar day more than the other at his return, Hence, if the Earth turned but once round its axis in a year, and if *that* turn was made the same way as the Earth goes round the Sun, there would be continual day on one side of the Earth, and continual night on the other

An absolute turn of the Earth on its axis never finishes a solar day.

Plate III, Fig. 2.

223 The first part of the preceding table shews how much of the celestial equator passes over the meridian in any given part of a mean solar day, and is to be understood the same way as the table in the 220th article The latter part, entitled, *Acceleration of the fixed Stars*, affords us an easy method of knowing whether or not our clocks and watches go true · for if, through a small hole in a window-shutter, or in a thin plate of metal fixed to a window, we observe at what time any star disappears behind a chimney, or corner of a house, at a little distance; and if the same star disappears the next night 3 minutes 56 seconds sooner

To know by the stars whether a clock goes true or not.

by the clock or watch, and on the second night, 7 minutes 52 seconds sooner, the third night 11 minutes 48 seconds sooner, and so on, every night, as in the table, which shews this difference for 30 natural days, it is an infallible sign that the machine goes true, otherwise it does not go true, and must be regulated accordingly, and as the disappearing of a star is instantaneous, we may depend on this information to half a second.

CHAP XIII

OF THE EQUATION OF TIME

224. THE Earth's motion on its axis being perfectly uniform and equal at all times of the year, the sidereal days are always precisely of an equal length, and so would the solar or natural days be, if the Earth's orbit were a perfect circle, and its axis perpendicular to its orbit. But the Earth's diurnal motion on an inclined axis, and its annual motion in an elliptic orbit, cause the Sun's apparent motion in the heavens to be unequal for sometimes he revolves from the meridian to the meridian again in somewhat less than 24 hours, shewn by a well-regulated clock, and at other times in somewhat more so that the time shewn by an equal going clock and a true sun dial is never the same but on the 15th of April, the 16th of June, the 31st of August, and the 24th of December. The clock, if it goes equably and true all the year round, will be before the Sun from the 24th of December till the 15th of April from that time till the 16th of June the Sun will be before the clock, from the 16th of June till the 31st of August the clock will be again before the Sun, and from thence to the 24th of December the Sun will be faster than the clock.

The Sun and clocks equal only on 4 days of the year.

225. The tables of the equation of natural days, at the end of the following chapter, shew the time that ought to be pointed out by a well-regulated clock or watch, every day of the year, at the precise moment of solar noon; that is, when the Sun's centre is on the meridian, or when a true sun-dial shews it to be precisely 12. Thus, on the 5th of January, in leap-year, when the Sun is on the me-

Use of the Equation Table.

ridian, it ought to be 5 minutes 51 seconds past 12 by the clock: and on the 15th of May, when the Sun is on the meridian, the time by the clock should be but 55 minutes 57 seconds past 11: in the former case, the clock is 5 minutes 51 seconds beforehand with the Sun; and in the latter case, the Sun is 4 minutes 3 seconds faster than the clock. The column at the right hand of each month shews the daily difference of this equation, as it increases or decreases. But without a meridian line, or a transit instrument fixed in the plane of the meridian, we cannot set a sun-dial true

226. The easiest and most expeditious way of drawing a meridian line is this: make four or five concentric circles, about a quarter of an inch from one another, on a flat board, about a foot in breadth; and let the outermost circle be but little less than the board will contain. Fix a pin perpendicularly in the centre, and of such a length that its whole shadow may fall within the innermost circle for at least 4 hours in the middle of the day. The pin ought to be about an 8th part of an inch thick, and to have a round blunt point. The board being set exactly level in a place where the Sun shines, suppose from 8 in the morning till 4 in the afternoon, about which hours the end of the shadow should fall without all the circles; watch the times in the forenoon when the extremity of the shortening shadow just touches the several circles, and *there* make marks. Then, in the afternoon of the same day, watch the lengthening shadow, and where its end touches the several circles in going over them, make marks also. Lastly, with a pair of compasses, find exactly the middle point between the two marks on any circle, and draw a straight line from the centre to that point; which line will be covered at noon by the shadow of a small upright wire, which should be put in the place of the pin. The reason for drawing several circles is, that in case one part of the day should prove clear, and the other part somewhat cloudy, if you miss the time when the point of the shadow should touch one circle, you may perhaps catch it in touching another. The best time for drawing a meridian line in this manner, is about the summer solstice, because the Sun changes his declination slowest, and his altitude fastest, in the longest days.

How to draw a meridian line.

If the casement of a window on which the Sun shines at noon be quite upright, you may draw a line along the edge of its

shadow on the floor, when the shadow of the pin is exactly on the meridian line of the board: and as the motion of the shadow of the casement will be much more sensible on the floor, than that of the shadow of the pin on the board, you may know to a few seconds when it touches the meridian line on the floor, and so regulate your clock for the day of observation by that line and the equation tables above mentioned, § 225

Equation of natural days explained.

227. As the equation of time, or difference between the time shewn by a well-regulated clock and a true sun-dial, depends upon two causes, namely, the obliquity of the ecliptic, and the unequal motion of the Earth in it, we shall first explain the effects of these causes separately considered, and then the united effects resulting from their combination.[1]

228. The Earth's motion on its axis being perfectly equable, or always at the same rate, and the[2] plane of the equator being perpendicular to its axis, it is evident that in equal times, equal portions of the equator pass over the meridian, and so would equal portions of the ecliptic, if it were parallel to, or coincident with, the equator. But, as the ecliptic is oblique to the equator, the equable motion of the Earth carries unequal portions of the ecliptic over the meridian in equal times, the difference being proportional to the obliquity; and as some parts of the ecliptic are much more oblique than others, those differences are unequal among themselves. Therefore, if two suns should start, either from the beginning of Aries or Libra, and continue to move through equal arcs in equal times, one in the equator, and the other in the ecliptic, the equatorial sun would always return to the meridian in 24 hours time, as measured by a well-regulated clock, but the sun in the ecliptic would return to the meridian sometimes sooner, and sometimes later than the equatorial sun, and only at the same moments with him on four days of the year, namely, the 20th of March, when the Sun enters Aries; the 21st of June, when

The first part of the equation of time.

[1] As the motion of the Earth is deranged by the action of the Moon, Venus, Mars, and Jupiter, the quantity of which is now computed, and employed in the calculation of the Sun's longitude, the equation of time must also be affected by this cause. At a maximum, however, it amounts only to 2½ seconds.—*Ed.*

[2] If the Earth were cut along the equator, quite through the centre, the flat surface of this section would be the plane of the equator; as the paper contained within any circle may be justly termed the plane of that circle.

he enters Cancer; the 23d of September, when he enters Libra; and the 21st of December, when he enters Capricorn. But as there is only one sun, and his apparent motion is always in the ecliptic, let us henceforth call him the real Sun, and the other, which is supposed to move in the equator, the fictitious; to which last the motion of a well-regulated clock always answers.

Let *Z* ♈ *z* ♎ be the Earth, *Z F R z* its axis, *a b c d e*, &c. the equator, *A B C D E*, &c. the northern half of the ecliptic from ♈ to ♎ on the side of the globe next the eye; and *M N O P*, &c. the southern half on the opposite side from ♎ to ♈. Let the points at *A*, *B*, *C*, *D*, *E*, *F*, &c. quite round from ♈ to ♈ again bound equal portions of the ecliptic, gone through in equal times by the real Sun; and those at *a*, *b*, *c*, *d*, *e*, *f*, &c. equal portions of the equator described in equal times by the fictitious sun; and let *Z* ♈ *z* be the meridian. Plate VI, Fig. 3.

As the real Sun moves obliquely in the ecliptic, and the fictitious sun directly in the equator, with respect to the meridian; a degree, or any number of degrees, between ♈ and *F* on the ecliptic, must be nearer the meridian *Z* ♈ *z*, than a degree, or any corresponding number of degrees, on the equator from ♈ to *f*; and the more so, as they are the more oblique; and, therefore, the true Sun comes sooner to the meridian every day whilst he is in the quadrant ♈ *F*, than the fictitious sun does in the quadrant ♈ *f*; for which reason, the solar noon precedes noon by the clock, until the real Sun comes to *F*, and the fictitious to *f*; which two points being equidistant from the meridian, both suns will come to it precisely at noon by the clock.

Whilst the real Sun describes the second quadrant of the ecliptic *FGHIKL* from ♋ to ♎, he comes later to the meridian every day than the fictitious sun moving through the second quadrant of the equator from *f* to ♎; for the points at *G*, *H*, *I*, *K*, and *L*, being farther from the meridian than their corresponding points at *g*, *h*, *i*, *k*, and *l*, they must be later of coming to it: and as both suns come at the same moment to the point ♎, they come to the meridian at the moment of noon by the clock.

In departing from Libra, through the third quadrant, the real Sun going through *MNOPQ* towards ♑ at *R*, and the fictitious sun through *m n o p q* towards *r*, the former comes to the meridian every day sooner than the latter, until the real Sun

comes to ♑, and the fictitious to *r*, and then they both come to the meridian at the same time.

Lastly, as the real Sun moves equably through *STUVW*, from ♑ towards ♈; and the fictitious sun through *s t u v w*, from *r*, towards ♈, the former comes later every day to the meridian than the latter, until they both arrive at the point ♈, and then they make it noon at the same time with the clock.

A table of the equation of time depending on the Sun's place in the ecliptic.

229. The annexed table shews how much the Sun is faster or slower than the clock ought to be, so far as the difference depends upon the obliquity of the ecliptic; of which the signs of the first and third quadrants are at the head of the table, and their degrees at the left hand; and in these the Sun is faster than the clock: the signs of the second and fourth quadrants are at the foot of the table, and their degrees at the right hand; in all which the sun is slower than the clock, so that entering the table with the given sign of the Sun's place at the head of the table, and the degree of his place in that sign at the left hand, or with the given sign at the foot of the table, and degree at the right hand; in the angle of meeting is the number of minutes and seconds that the Sun is faster or slower than the clock or, in other words, the quantity of time in which the real Sun, when in that part of the ecliptic, comes sooner or later to the meridian than the fictitious sun in the equator. Thus, when the Sun's place is ♉ Taurus 12, he is 9 minutes 49 seconds faster than the clock; and when his place is ♋ Cancer 18°, he is 6 minutes 2 seconds slower [3]

[3] The Editor has computed the following table anew, upon the supposition that the obliquity of the ecliptic is 23° 27′ 51. When the obliquity of the ecliptic increases or diminishes, the equation of time will also increase or diminish, but by a quantity so very small, that it amounts, at a maximum, to about *a second and a half* in the course of two centuries. The signs + and — indicate that this part of the equation of time is to be added to or subtracted from the apparent time. The numbers in this table are the differences between the true longitude of the Sun, and his true right ascension, converted into time, at the rate of 15° per hour.—*Ed.*

A Table of the equation of time depending on the obliquity of the ecliptic.

Sun faster than the Clock in				
	♈— ♎—	♉— ♏—	♊— ♐—	1st Q. 3d Q
Degrees	Min Sec	Min Sec	Min Sec	Degrees
0	0 [illegible]	8 23	8 45	30
1	0 20	8 33	8 34	29
2	0 40	8 43	8 24	28
3	1 0	8 52	8 12	27
4	1 19	9 1	8 0	26
5	1 39	9 9	7 47	25
6	1 58	9 16	7 34	24
7	2 18	9 23	7 20	23
8	2 37	9 29	7 5	22
9	2 56	9 35	6 50	21
10	3 15	9 39	6 34	20
11	3 34	9 43	6 18	19
12	3 52	9 47	6 1	18
13	4 10	9 49	5 41	17
14	4 28	9 51	5 26	16
15	4 46	9 53	5 8	15
16	5 31	9 53	4 50	14
17	5 20	9 53	4 31	13
18	5 37	9 52	4 11	12
19	5 53	9 50	3 51	11
20	6 9	9 48	3 31	10
21	6 25	9 45	3 11	9
22	6 40	9 41	2 51	8
23	6 54	9 37	2 30	7
24	7 8	9 31	2 9	6
25	7 22	9 25	1 48	5
26	7 35	9 19	1 26	4
27	7 48	9 11	1 5	3
28	8 0	9 3	0 43	2
29	8 12	8 54	0 22	1
30	8 23	8 45	0 0	0
2d Q 4th Q	♍ + ♓ +	♌ + ♒ +	♋ + ♑ +	Deg
Sun slower than the Clock in				

230. This part of the equation of time may perhaps be somewhat difficult to understand by a figure, because both halves of the ecliptic seem to be on the same side of the globe, but it may be made very easy to any person who has a real globe before him, by putting small patches on every 10th or 15th degree both of the equator and ecliptic, beginning at Aries ♈, and then turning the ball slowly round westward, he will see all the patches from Aries to Cancer come to the brazen meridian sooner than the corresponding patches on the equator; all those from Cancer to Libra will come later to the meridian than their corresponding patches on the equator, those from Libra to Capricorn sooner, and those from Capricorn to Aries later, and the patches at the beginnings of Aries, Cancer, Libra, and Capricorn, being either on or even with those on the equator, shew that the two suns either meet there, or are even with one another, and so come to the meridian at the same moment.

Plate III, Fig. 3.

A machine for shewing the sydereal, the equal, and the solar time.

231 Let us suppose that there are two little balls moving equably round a celestial globe by clock-work, one always keeping in the ecliptic, and gilt with gold, to represent the real Sun, and the other keeping in the equator, and silvered, to represent the fictitious sun, and that whilst these balls move once round the globe according to the order of signs, the clock turns the globe 366 times round its axis westward. The stars will make 366 diurnal revolutions from the brazen meridian to it again, and the two balls representing the real and fictitious suns always going farther eastward from any given star, will come later than it to the meridian every following day, and each ball will make 365 revolutions to the meridian, coming equally to it at the beginnings of Aries, Cancer, Libra, and Capricorn, but in every other point of the ecliptic, the gilt ball will come either sooner or later to the meridian than the silvered ball, like the patches above mentioned. This would be a pretty enough way of shewing the reason why any given star, which, on a certain day of the year, comes to the meridian with the Sun, passes over it so much sooner every following day, as on that day twelvemonth to come to the meridian with the Sun again, and also to shew the reason why the real Sun comes to the meridian sometimes sooner, sometimes later, than it is noon by the clock; and, on four days of the year at the same time, whilst

the fictitious sun always comes to the meridian when it is 12 at noon by the clock. This would be no difficult task for an artist to perform, for the gold ball might be carried round the ecliptic by a wire from its north pole, and the silver ball round the equator by a wire from its south pole, by means of a few wheels to each, which might be easily added to my improvement of the celestial globe, described in No. 483 of the Philosophical Transactions, and of which I shall give a description in the latter part of this book, from the third figure of the third plate.

232. It is plain, that if the ecliptic were more obliquely posited to the equator, as the dotted circle ♈ *x* ♎, the equal divisions from ♈ to *x* would come still sooner to the meridian *Z o*, ♈ than those marked *A*, *B*, *C*, *D*, and *E* do; for two divisions containing 30°, from ♈ to the second dot, a little short of the figure 1, come sooner to the meridian than one division containing only 15° from ♈ to *A* does, as the ecliptic now stands, and those of the second quadrant from *x* to ♎ would be so much later. The third quadrant would be as the first, and the fourth as the second. And it is likewise plain, that where the ecliptic is most oblique, namely, about Aries and Libra, the difference would be greatest, and least about Cancer and Capricorn, where the obliquity is least. Plate VI, Fig. 3.

233. Having explained one cause of the difference of time shewn by a well-regulated clock and a true sun-dial; and considered the Sun, not the Earth, as moving in the ecliptic; we now proceed to explain the other cause of this difference, namely, the inequality of the Sun's apparent motion, § 205, which is slowest in summer, when the Sun is farthest from the Earth, and swiftest in winter when he is nearest to it. But the Earth's motion on its axis is equable all the year round, and is performed from west to east, which is the way that the Sun appears to change his place in the ecliptic.

The second part of the equation of time.

234. If the Sun's motion were equable in the ecliptic, the whole difference between the equal time as shewn by the clock, and the unequal time as shewn by the Sun, would arise from the obliquity of the ecliptic. But the Sun's motion sometimes exceeds a degree in 24 hours, though generally it is less; and when his motion is slowest, any particular meridian will revolve sooner to him than when his motion is quickest, for it will over-

take him in less time when he advances a less space than when he moves through a larger.

235. Now, if there were two suns moving in the plane of the ecliptic, so as to go round it in a year; the one describing an equal arc every 24 hours, and the other describing sometimes a less arc in 24 hours, and at other times a larger, gaining at one time of the year what it lost at the opposite; it is evident that either of these suns would come sooner or later to the meridian than the other, as it happened to be behind or before the other; and when they were both in conjunction, they would come to the meridian at the same moment.

Plate VI, Fig. 4. 236. As the real Sun moves unequably in the ecliptic, let us suppose a fictitious sun to move equably in a circle coincident with the plane of the ecliptic. Let *A B C D* be the ecliptic or orbit in which the real Sun moves, and the dotted circle *a b c d* the imaginary orbit of the fictitious sun; each going round in a year according to the order of letters, or from west to east. Let *H I K L* be the Earth turning round its axis the same way every 24 hours; and suppose both suns to start from *A* and *a* in a right line with the plane of the meridian *E H*, at the same moment: the real Sun at *A* being then at his greatest distance from the Earth, at which time his motion is slowest; and the fictitious sun at *a*, whose motion is always equable, because his distance from the Earth is supposed to be always the same. In the time that the meridian revolves from *H* to *H* again, according to the order of the letters *H I K L*, the real Sun has moved from *A* to *F*, and the fictitious with a quicker motion from *a* to *f* through a larger arc; therefore, the meridian *E H* will revolve sooner from *H* to *h* under the real Sun at *F*, than from *H* to *k* under the fictitious sun at *f*; and consequently it will then be noon by the sun-dial sooner than by the clock.

As the real Sun moves from *A* towards *C*, the swiftness of his motion increases all the way to *C*, where it is at the quickest. But, notwithstanding this, the fictitious sun gains so much upon the real, soon after his departing from *A*, that the increasing velocity of the real Sun does not bring him up with the equally-moving fictitious sun, till the former comes to *C*, and the latter to *c*, when each has gone half round its respective orbit; and then being in conjunction, the meridian *E H* re-

volving to E K comes to both suns at the same time, and therefore it is noon by them both at the same moment.

But the increased velocity of the real Sun, now being at the quickest, carries him before the fictitious one; and, therefore, the same meridian will come to the fictitious sun sooner than to the real: for, whilst the fictitious sun moves from c to g, the real Sun moves through a greater arc from C to G: consequently the point K has its noon by the clock when it comes to k, but not its noon by the Sun till it comes to l. And although the velocity of the real Sun diminishes all the way from C to A, and the fictitious sun by an equable motion is still coming nearer to the real Sun, yet they are not in conjunction till the one comes to A and the other to a; and then it is noon by them both at the same moment.

Thus, it appears that the solar noon is always later than noon by the clock whilst the Sun goes from C to A; sooner whilst he goes from A to C, and at these two points the Sun and clock being equal, it is noon by them both at the same moment.

237 The point A is called *the Sun's apogee*, because when he is there, he is at his greatest distance from the Earth; the point C his *perigee*, because when in it he is at his least distance from the Earth: and a right line, as A E C drawn through the Earth's centre, from one of these points to the other, is called *the line of the apsides*. Apogee, Perigee, and Apsides, what. Plate VI, Fig. 4.

238 The distance that the Sun has gone in any time from his apogee (not the distance he has to go to it, though ever so little), is called *his mean anomaly*, and is reckoned in signs and degrees, allowing 30 degrees to a sign. Thus, when the Sun has gone, suppose 174 degrees from his apogee at A, he is said to be 5 signs 24 degrees from it, which is his mean anomaly, and when he is gone, suppose 355 degrees from his apogee, he is said to be 11 signs 25 degrees from it, although he be but 5 degrees short of A in coming round to it again. Mean anomaly, what

239 From what was said above, it appears, that when the Sun's anomaly is less than 6 signs, that is, when he is anywhere between A and C, in the half A B C of his orbit, the solar noon precedes the clock noon, but when his anomaly is more

than 6 signs, that is, when he is anywhere between *C* and *A*, in the half *C D A*, of his orbit, the clock noon precedes the solar. When his anomaly is 0 signs 0 degrees, that is when he is in his apogee at *A*, or 6 signs 0 degrees, which is, when he is in his perigee at *C*; he comes to the meridian at the moment that the fictitious sun does, and then it is noon by them both at the same instant.

240. The following table shews the variation, or equation, of time depending on the Sun's anomaly, and arising from his unequal motion in the ecliptic, as the former table, § 229, shews the variation depending on the Sun's place, and resulting from the obliquity of the ecliptic; this is to be understood the same way as the other, namely, that when the signs are at the head of the table, the degrees are at the left hand, but when the signs are at the foot of the table, the respective degrees are at the right hand; and in both cases the equation is in the angle of meeting. When both the above-mentioned equations are either faster or slower, their sum is the absolute equation of time; but when the one is faster, and the other slower, it is their difference. Thus, suppose the equation depending on the Sun's place, be 6 minutes 41 seconds too slow, and the equation depending on the Sun's anomaly, be 4 minutes 20 seconds too slow, their sum is 11 minutes 1 second too slow. But if the one had been 6 minutes 41 seconds too fast, and the other 4 minutes 20 seconds too slow, their difference would have been 2 minutes 21 seconds too fast, because the greater quantity is too fast.[4]

[4] The following Table, which is nothing more than the equation of the Sun's orbit, or the difference between his mean and true place, converted into time, has been computed anew from the accurate Solar Tables of M. Delambre, and adapted to the year 1802. But as the equation of the solar orbit diminishes at the rate of 18″.8 in a century, this part of the equation of time will diminish at the rate of 1″.25 in a century. There is also another variation in the equation of time, arising from the motion of the Sun's apogee, and amounting, at a maximum, to 14″.3 in a century, when the Sun is in the apogeal or perigeal points of his orbit, but for common these variations may be safely neglected.—*Ed.*

A TABLE OF THE EQUATION OF TIME, DEPENDING ON THE SUN'S ANOMALY.

Sun faster than the Clock if his Anomaly be													
	0 Signs.		I. —		II. —		III. —		IV. —		V. —		
D.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	D.
0	0	0	3	47	6	36	7	42	6	44	3	55	30
1	0	8	3	54	6		7	42	6	40	3	48	29
2	0	16	4	0	6	40	7	42	6	36	3	41	28
3	0	[illegible]	4	7	6	44	7	12	6	32	3	34	27
4	0	[illegible]	4	14	6	47	7	41	6	27	3	26	26
5	0	39	4	20	6	51	7	41	6	23	3	19	25
6	0	17	4	27	6	55	7	40	6	18	3	12	24
7	0	55	4	33	6	58	7	39	6	13	3	4	23
8	1	3	4	40	7	1	7	38	6	9	2	56	22
9	1	11	4	46	7	5	7	37	6	4	2	49	21
10	1	19	4	52	7	8	7	36	5	58	2	43	20
11	1	26	4	58	7	11	7	35	5	53	2	33	19
12	1	34	5	4	7	14	7	34	5	48	2	26	18
13	1	42	5	10	7	16	7	32	5	43	2	18	17
14	1	49	5	16	7	19	7	30	5	37	2	10	16
15	1	57	5	22	7	21	7	28	5	31	2	2	15
16	2	5	5	27	7	23	7	26	5	26	1	54	14
17	2	12	5	33	7	26	7	24	5	20	1	46	13
18	2	20	5	38	7	28	7	22	5	14	1	38	12
19	2	27	5	44	7	30	7	20	5	8	1	30	11
20	2	35	5	49	7	31	7	17	5	2	1	22	10
21	2	42	5	54	7	33	7	14	4	55	1	14	9
22	2	50	5	59	7	34	7	11	4	49	1	6	8
23	2	57	6	4	7	36	7	8	4	43	0	58	7
24	3	4	6	9	7	37	7	5	4	36	0	49	6
25	3	12	6	14	7	38	7	2	4	30	0	41	5
26	3	19	6	16	7	39	6	59	4	23	0	33	4
27	3	26	6	23	7	40	6	55	4	16	0	25	3
28	3	33	6	27	7	41	6	52	4	9	0	17	2
29	3	40	6	32	7	41	6	48	4	2	0	8	1
30	3	47	6	36	7	42	6	44	3	55	0	0	0
D.	XI Signs		X. +		IX +		VIII +		VII. +		VI. +		D.
Sun slower than the Clock if his Anomaly be													

242. The obliquity of the ecliptic to the equator, which is the first mentioned cause of the equation of time, would make the Sun and clocks agree on 4 days of the year; which are when the Sun enters Aries, Cancer, Libra, and Capricorn; but the other cause, now explained, would make the Sun and clocks equal only twice in a year; that is, when the Sun is in his apogee and perigee. Consequently, when these two points fall in the beginnings of Cancer and Capricorn, or of Aries and Libra, they concur in making the Sun and clocks equal in these points. But the apogee at present is in the 9th degree of Cancer, and the perigee in the 9th degree of Capricorn, and, therefore, the Sun and clocks cannot be equal about the beginnings of these signs, nor at any time of the year, except when the swiftness or slowness of the equation resulting from one cause just balances the slowness or swiftness arising from the other.

243. The second table in the following chapter shews the Sun's place in the ecliptic at the noon of every day by the clock, for the second year after leap-year; and also the Sun's anomaly to the nearest degree, neglecting the odd minutes of that degree. Its use is only to assist in the method of making a general equation table from the two fore-mentioned tables of equation depending on the Sun's place and anomaly, § 229, 241; concerning which method we shall give a few examples presently. The next following tables are made from those two; and shew the absolute equation of time resulting from the combination of both its causes; in which the minutes, as well as degrees, both of the Sun's place and anomaly are considered. The use of these tables is already explained (§ 225); and they serve for every day in leap-year, and the 1st, 2d, and 3d years after: for, on most of the same days of all these years, the equation differs, because of the odd 6 hours more than the 365 days of which the year consists.

Examples for making Equation Tables.

Example I. On the 15th of April, the Sun is in the 25th degree of ♈ Aries, and his anomaly is 9 signs 15 degrees; the equation resulting from the former is 7 minutes 22 seconds of time too fast, (§ 229); and from the latter, 7 minutes 21 seconds too slow (§ 241); the difference is 1 second that the Sun is too slow at the noon of that day, taking it in gross for the degrees of the Sun's place and anomaly, without making proportionable al-

lowance for the odd minutes. Hence, at noon, the swiftness of the one equation balancing so nearly the slowness of the other, makes the Sun and clocks equal on some part of that day.

Example II. On the 16th of June, the Sun is in the 25th degree of ♊ Gemini, and his anomaly is 11 signs 16 degrees; the equation arising from the former is 1 minute 48 seconds too fast, and from the latter, 1 minute 49 seconds too slow; which balancing one another at noon to 1 second, the Sun and clocks are again equal on that day.

Example III. On the 31st of August, the Sun's place is 7 degrees 52 minutes of ♍ Virgo, (which we call the 8th degree, as it is so near) and his anomaly is 2 signs 0 degrees; the equation arising from the former, is 6 minutes 40 seconds too slow; and from the latter, 6 minutes 36 seconds too fast, the difference being only 4 seconds too slow at noon, and decreasing towards an inequality, will make the Sun and clocks equal in the afternoon of that day.

Example IV. On the 23d of December, the Sun's place is 1 degree 41 minutes (call it 2 degrees) of ♑ Capricorn, and his anomaly is 5 signs 23 degrees; the equation for the former is 43 seconds too slow, and for the latter, 58 seconds too fast; the difference is 15 seconds too fast at noon, which decreasing will come to an equality, and so make the Sun and clocks equal in the evening of that day.

And thus we find, that on some part of each of the above-mentioned four days, the Sun and clocks are equal; but if we work examples for all other days of the year, we shall find them different. And,

Remark.

211. On those days which are equidistant from any equinox or solstice, we do not find that the equation is as much too fast or too slow on the one side, as it is too slow or too fast on the other. The reason is, that the line of the apsides (§ 238), does not at present fall either into the equinoctial or solstitial points (§ 242).

The reason why equation tables are but temporary.

245. The four following equation tables for leap-year, and the first, second, and third years after, would serve for ever, if the Sun's place and anomaly were always the same on every given day of the year as on the same day four years before or after. But since that is not the case, no general equation tables can be so constructed as to be perpetual.

CHAP. XIV.

OF THE PRECESSION OF THE EQUINOXES

246. It has been already observed (§ 116), that by the Earth's motion on its axis, there is more matter accumulated all around the equatorial parts than anywhere else on the Earth. The Sun and Moon, by attracting this redundancy of matter, bring the equator sooner under them in every return towards it, than if there was no such accumulation. Therefore, if the Sun sets out as from any star or other fixed point in the heavens, the moment when he is departing from the equinoctial or from either tropic, he will come to the same equinox or tropic again 20 minutes 17½ seconds of time, or 50 seconds of a degree, before he completes his course, so as to arrive at the same fixed star or point from whence he set out. For the equinoctial points recede 50 seconds of a degree westward every year, contrary to the Sun's annual progressive motion.

When the Sun arrives at the same [1] equinoctial or solstitial point, he finishes what we call the tropical year, which by observation is found to contain 365 days 5 hours 48 minutes 57 seconds; and when he arrives at the same fixed star again, as seen from the Earth, he completes the sydereal year, which contains 365 days 6 hours 9 minutes 14½ seconds. The sydereal year is therefore 20 minutes 17½ seconds longer than the solar or tropical year, and 9 minutes 14½ seconds longer than the Julian or civil year, which we state at 365 days 6 hours, so that the civil year is almost a mean betwixt the sydereal and tropical.

247. As the Sun describes the whole ecliptic, or 360 degrees in a tropical year, he moves 59 minutes 8 seconds of a degree every day at a mean rate, and consequently 50 seconds of a degree in 20 minutes 17½ seconds of time, therefore he will arrive at the same equinox or solstice when he is 50 seconds of a degree short of the same star or fixed point in the heavens,

[1] The two opposite points in which the ecliptic crosses the equinoctial, are called the *Equinoctial points*; and the two points where the ecliptic touches the tropics (which are likewise opposite, and 90 degrees from the former) are called the *Solstitial points*.

from which he set out in the year before. So that with respect to the fixed stars, the Sun and equinoctial points fall back (as it were) 30 degrees in 2160 years, which will make the stars appear to have gone 30 degrees forward with respect to the signs of the ecliptic in that time, for the same signs always keep in the same points of the ecliptic without regard to the constellations.

To explain this by a figure, let the Sun be in conjunction with a fixed star at *S*, suppose in the 30th degree of ♉, on the 21st day of May 1756. Then making 2160 revolutions through the ecliptic *VWX*, at the end of so many sydereal years, he will be found again at *S*; but at the end of so many Julian years, he will be found at *M*, short of *S*; and at the end of so many tropical years, he will be found short of *M*, in the 30th degree of Taurus at *T*, which has receded back from *S* to *T* in that time, by the precession of the equinoctial points ♈ Aries and ♎ Libra. The arc *ST* will be equal to the amount of the precession of the equinox in 2160 years, at the rate of 50″ of a degree, or 20 minutes 17½ seconds of time annually; this, in so many years, makes 30 days 10½ hours, which is the difference between 2160 sydereal and tropical years. And the arc *MT* will be equal to the space moved through by the Sun in 2160 times, 11 minutes three seconds, or 16 days 13 hours 48 minutes, which is the difference between 2160 Julian and tropical years.

Plate VI, Fig. 4.

A Table shewing the Precession of the Equinoctial Points in the Heavens, both in Motion and Time, and the anticipation of the Equinoxes on Earth.

Julian years.	Precession of the Equinoctial Points in the Heavens. Motion.				Time.				Anticipation of the Equinoxes on the Earth.			
	S.	°	′	″	D.	H.	M.	S.	D.	H.	M.	S.
1	0	0	0	50	0	0	20	17½	0	0	11	3
2	0	0	1	40	0	0	40	35	0	0	22	6
3	0	0	2	30	0	1	0	52½	0	0	33	9
4	0	0	3	20	0	1	21	10	0	0	44	12
5	0	0	4	10	0	1	41	27½	0	0	55	15
6	0	0	5	0	0	2	1	45	0	1	6	18
7	0	0	5	50	0	2	22	2½	0	1	17	21
8	0	0	6	40	0	2	42	20	0	1	28	24
9	0	0	7	30	0	3	2	37½	0	1	39	27
10	0	0	8	20	0	3	22	55	0	1	50	30
20	0	0	16	40	0	6	45	50	0	3	41	0
30	0	0	25	0	0	10	8	45	0	5	31	30
40	0	0	33	20	0	13	31	40	0	7	22	0
50	0	0	41	40	0	16	54	35	0	9	12	30
60	0	0	50	0	0	20	17	30	0	11	3	0
70	0	0	58	20	0	23	40	25	0	12	53	30
80	0	1	6	40	1	3	3	20	0	14	44	0
90	0	1	15	0	1	6	20	15	0	16	34	30
100	0	1	23	20	1	9	49	10	0	18	25	0
200	0	2	40	40	2	19	38	20	1	12	50	0
300	0	4	10	0	4	5	27	30	2	7	15	0
400	0	5	33	20	5	15	16	40	3	1	40	0
500	0	6	56	40	7	1	5	50	3	20	5	0
600	0	8	20	0	8	10	55	0	4	14	30	0
700	0	9	43	20	9	20	44	10	5	8	55	0
800	0	11	6	40	11	6	33	20	6	3	20	0
900	0	12	30	0	12	16	22	30	6	21	45	0
1000	0	13	53	20	14	2	11	40	7	16	10	0
2000	0	27	46	40	28	4	23	20	15	8	20	0
3000	1	11	40	0	42	6	35	0	23	0	30	0
4000	1	25	33	20	56	8	40	40	30	10	40	0
5000	2	9	26	40	70	10	58	20	38	8	50	0
6000	2	23	20	0	84	13	10	0	46	1	0	0
7000	3	7	13	20	98	15	21	40	53	17	10	0
8000	3	2	6	40	112	17	33	20	61	0	20	0
9000	4	5	0	0	126	19	45	0	69	1	30	0
10000	4	18	53	20	140	21	56	40	76	17	40	0
20000	9	7	46	40	281	19	53	20	153	11	20	0
30000	12	0	0	0	365	6	0	0	108	21	36	0

248. From the shifting of the equinoctial points, and with them all the signs of the ecliptic, it follows, that those stars which in the infancy of astronomy were in Aries are now got into Taurus, those of Taurus into Gemini, &c. Hence, likewise, it is, that the stars which rose or set at any particular season of the year, in the times of Hesiod, Eudoxus, Virgil, Pliny, &c. by no means answer at this time to their descriptions. The preceding table shews the quantity of this shifting both in the heavens and on the Earth, for any number of years to 25,920, which completes the grand celestial period, within which any number and its quantity is easily found; as in the following example, for 5763 years, which at the autumnal equinox, A. D. 1756, is thought to be the age of the world. So that with regard to the fixed stars, the equinoctial points in the heavens have receded $2^s\ 20°\ 2'\ 30''$ since the creation, which is as much as the Sun moves in $81^d\ 5^h\ 0^m\ 52^s$. And since that time, or in 5763 years, the equinoxes with us have fallen back $44^d\ 5^h\ 21^m\ 9^s$, hence, reckoning from the time of the Julian equinox, A. D. 1756, viz September 11th, it appears that the autumnal equinox at the creation was on the 25th of October.

Julian years.	Precession of the Equinoctial Points in the Heavens. Motion.				Time.				Anticipation of the Equinoxes on the Earth.			
	S.	°	′	″	D.	H.	M.	S.	D.	H.	M.	S.
5000	2	9	26	10	70	10	58	20	38	8	50	0
700	0	9	43	20	9	20	44	10	5	8	55	0
60	0	0	50	0	0	20	17	30	0	11	3	0
3	0	0	2	30	0	1	0	52	0	0	33	9
5763	2	20	2	30	81	5	0	52	44	5	21	9

249. The anticipation of the equinoxes, and consequently of the seasons, is by no means owing to the precession of the equinoctial and solstitial points in the heavens (which can only affect the apparent motions, places, and declinations, of the fixed stars), but to the difference between the civil and solar year, which is 11 minutes 3 seconds, the civil year containing 365 days 6 hours, and the solar year 365 days 5 hours 48 minutes 57 seconds.

The anticipation of the equinoxes and seasons.

The next following table, page 135, shews the length, and consequently the difference of any number of sydereal, civil, and solar years, from 1 to 10,000.

The reason for altering the style.

250. The above 11 minutes 3 seconds, by which the civil or Julian year exceeds the solar, amounts to 11 days in 1433 years; and so much our seasons have fallen back with respect to the days of the months, since the time of the Nicene council in A. D. 325, and therefore, in order to bring back all the fasts and festivals to the days then settled, it was requisite to suppress 11 nominal days. And that the same seasons might be kept to the same times of the year for the future, to leave out the bissextile day in February at the end of every century of years not divisible by 4, reckoning them only common years, as the 17th, 18th, and 19th centuries, viz. the years 1700, 1800, 1900, &c. because a day intercalated every fourth year was too much, and retaining the bissextile-day at the end of those centuries of years which are divisible by 4, as the 16th, 20th, and 24th centuries, viz the years 1600, 2000, 2400, &c. Otherwise, in length of time, the seasons would be quite reversed with regard to the months of the year, though it would have required near 23,783 years to have brought about such a total change. If the Earth had made exactly 365¼ diurnal rotations on its axis, whilst it revolved from any equinoctial or solstitial point to the same again, the civil and solar years would always have kept pace together, and the style would never have needed any alteration.

The precession of the equinoctial points.

251. Having already mentioned the cause of the precession of the equinoctial points in the heavens (§ 246), which occasions a slow deviation of the Earth's axis from its parallelism, and thereby a change of the declination of the stars from the equator, together with a slow apparent motion of the stars forward with respect to the signs of the ecliptic, we shall now explain the phenomena by a diagram.

Plate VI, Fig. 6.

Let *NZSVL* be the Earth, *SONA* its axis produced to the starry heavens, and terminating in *A*, the present north pole of the heavens, which is vertical to *N* the north pole of the Earth. Let *EOQ* be the equator, *T* ♋ *Z* the tropic of Cancer, and *VT* ♑ the tropic of Capricorn: *VOZ*

the ecliptic, and *BO* its axis, both which are immoveable among the stars. But as the equinoctial[2] points recede in the ecliptic, the Earth's axis *SON* is in motion upon the Earth's centre *O*, in such a manner as to describe the double cone *NOn* and *SOs* round the axis of the ecliptic *BO*, in the time that the equinoctial points move quite round the ecliptic, which is 25,920 years, and in that length of time the north pole of the Earth's axis produced describes the circle *ABCDA* in the starry heavens, round the pole of the ecliptic, which keeps immoveable in the centre of that circle. The Earth's axis being 23½ degrees inclined to the axis of the ecliptic, the circle *ABCDA* described by the north pole of the Earth's axis produced to *A*, is 47 degrees in diameter, or double the inclination of the Earth's axis. In consequence of this, the point *A*, which at present is the north pole of the heavens, and near to a star of the second magnitude in the tail of the constellation called the Little Bear, must be deserted by the Earth's axis, which, moving backwards a degree every 72 years, will be directed towards the star or point *B* in 6480 years hence, and in double of that time, or 12,960 years, it will be directed towards the star or point *C*, which will then be the north pole of the heavens, although it is at present 8½ degrees south of the zenith of London *L*. The present position of the equator *EOQ*, will then be changed into *eOq*, the tropic of Cancer *T* ♋ *Z* into *Vt* ♋, and the tropic of Capricorn *Vt* ♑ into *t* ♑ *Z*, as is evident by the figure. And the Sun, in the same part of the heavens where he is now over the earthly tropic of Capricorn, and makes the shortest days and longest nights in the northern hemisphere, will then be over the earthly tropic of Cancer, and make the days longest and nights shortest. So that it will require 12,960 years yet more, or 25,920 from the then present time, to bring the north pole N quite round, so as to be directed toward that point of the heavens which is vertical to it at present. And then, and not till then, the same stars which at present describe the equator, tropics, and polar circles, &c. by the Earth's diurnal motion, will describe them over again.

[2] The equinoctial circle intersects the ecliptic in two opposite points, called Aries and Libra, from the signs which always keep in these points; they are called the equinoctial points, because when the Sun is in either of them, he is directly over the terrestrial equator, and then the days and nights are equal.

N. B. As the sydereal year is now found from the most accurate observations to be only 365^d 6^h 9′ 11″.6, the first part of the following table, containing the sydereal years, will err in excess 2″.9 for every year. If *n*, therefore, be the number of civil years for which the sydereal time is required, *n* × 2″.9 will be the correction to be added to the time given by the table. Thus, if we want the sydereal time for 60 years, the table gives 21915^d 9^h 14′ 30″; but *n* being in this case equal to 60, the correction *n* × 2″.9 will be equal to 60 × 2″.9, or 174″, or 2′ 54″, so that the true sydereal time will be 21915^d 9^h 17′ 24″.

The solar year being only 365^d 5^h 48′ 48″, the 2d part of the table containing solar time will err 9′ in excess for every year, so that *n* being the number of years as before, *n* × 9′ will be the correction which is always to be added to the time given by the table.—*Ed.*

TABLES

A Table shewing the Time contained in any number of Sydereal, Julian, and Solar Years, from 1 to 10000.

Sydereal Years.					Julian Years.		Solar Years.			
Years.	Days.	H.	M.	S.	Days.	H.	Days.	H.	M.	S
1	365	6	9	14½	365	6	365	5	48	57
2	730	12	18	29	730	12	730	11	37	54
3	1095	18	27	43½	1095	18	1095	17	26	51
4	1461	0	36	58	1461	0	1460	23	15	48
5	1826	6	46	12½	1826	6	1826	5	4	45
6	2191	12	55	27	2191	12	2191	10	53	42
7	2556	19	5	41½	2556	18	2556	16	42	39
8	2922	1	13	56	2922	0	2921	22	31	36
9	3287	7	23	10½	3287	6	3287	4	20	33
10	3652	13	32	25	3652	12	3652	10	9	0
20	7305	3	4	50	7305	0	7304	20	19	0
30	10957	16	37	15	10957	12	10957	6	28	30
40	14610	6	9	40	14610	0	14609	16	38	0
50	18262	19	42	5	18262	12	18262	2	47	0
60	21915	9	14	30	21915	6	21914	12	57	0
70	25567	22	46	55	25567	12	25566	23	6	30
80	29220	12	19	20	29220	0	29219	9	16	0
90	32873	1	51	45	32872	12	32871	19	25	30
100	36525	15	24	10	36525		36524	5	35	
200	73051	6	48	20	73050		73048	11	10	
300	109576	22	12	30	109575		109572	16	45	
400	146102	13	36	40	146100		146096	22	20	
500	182628	5	0	50	182625		182621	3	55	
600	219153	20	25		219150		219145	9	30	
700	255679	11	49	10	255675		255669	15	5	
800	292205	3	13	20	292200		292193	20	40	
900	328730	18	37	30	328725		328718	2	15	
1000	365256	10	1	40	365250		365242	7	50	
2000	730512	20	3	20	730500		730484	15	40	
3000	1095769	6	5		1095750		1095726	23	30	
4000	1461025	16	6	40	1461000		1460969	7	20	
5000	1826282	2	8	20	1826250		1826211	15	10	
6000	2191538	12	10		2191500		2191453	23	0	
7000	2556794	22	11	40	2556750		2556696	6	50	
8000	2922051	8	13	20	2922000		2921938	14	10	
9000	3287037	18	15		3287250		3287180	22	30	
10000	3652564	4	16	40	3652500		3652423	0	20	

A Table shewing the Sun's true Place and Distance from his Apogee, for the second year after Leap-year.

Days.	January. Sun's Place. D.	M.	Sun's Anomaly. S.	D.	February. Sun's Place. D.	M.	Sun's Anomaly. S.	D.	March. Sun's Place. D.	M.	Sun's Anomaly. S.	D.	April.* Sun's Place. D.	M.	Sun's Anomaly. S.	D.	May. Sun's Place. D.	M.	Sun's Anomaly. S.	D.	June. Sun's Place. D.	M.	Sun's Anomaly. S.	D.
1	11 ♑	7	6	2	12 ♒	39	7	3	10 ♓	53	8	0	11 ♈	40	9	1	10 ♉	57	10	0	10 ♊	46	11	1
2	12	8	6	3	13	40	7	4	11	53	8	1	12	39	9	2	11	55	10	1	11	44	11	2
3	13	9	6	4	14	41	7	5	12	53	8	2	13	38	9	3	12	53	10	2	12	41	11	3
4	14	10	6	5	15	42	7	6	13	53	8	3	14	37	9	4	13	51	10	3	13	38	11	4
5	15	11	6	6	16	43	7	7	14	53	8	4	15	36	9	5	14	49	10	4	14	35	11	5
6	16	12	6	7	17	43	7	8	15	53	8	5	16	35	9	6	15	47	10	5	15	33	11	6
7	17	14	6	8	18	44	7	9	16	53	8	6	17	34	9	7	16	45	10	6	16	30	11	7
8	18	15	6	9	19	45	7	10	17	53	8	7	18	33	9	8	17	43	10	7	17	28	11	8
9	19	16	6	10	20	46	7	11	18	53	8	8	19	32	9	9	18	41	10	8	18	25	11	9
10	20	17	6	11	21	46	7	12	19	53	8	9	20	30	9	10	19	39	10	9	19	22	11	10
11	21	18	6	12	22	47	7	13	20	52	8	10	21	29	9	11	20	37	10	10	20	20	11	11
12	22	19	6	13	23	47	7	14	21	52	8	11	22	28	9	12	21	34	10	11	21	17	11	12
13	23	21	6	14	24	48	7	15	22	52	8	12	23	26	9	13	22	32	10	12	22	14	11	13
14	24	22	6	15	25	48	7	16	23	52	8	13	24	25	9	14	23	30	10	13	23	11	11	14
15	25	23	6	16	26	49	7	17	24	51	8	14	25	24	9	15	24	28	10	14	24	8	11	15
16	26	24	6	17	27	49	7	18	25	51	8	15	26	22	9	16	25	26	10	15	25	6	11	16
17	27	25	6	18	28	50	7	19	26	51	8	16	27	21	9	17	26	23	10	16	26	3	11	17
18	28	26	6	19	29	50	7	20	27	50	8	17	28	19	9	18	27	21	10	17	27	0	11	18
19	29	27	6	20	♓	51	7	21	28	50	8	18	29	18	9	19	28	19	10	18	27	58	11	18
20	♒	28	6	21	1	51	7	22	29	49	8	19	♉	17	9	20	29	16	10	19	28	55	11	19
21	1	29	6	22	2	51	7	23	♈	49	8	20	1	15	9	21	♊	14	10	20	29	52	11	20
22	2	30	6	23	3	52	7	24	1	48	8	21	2	13	9	22	1	11	10	21	♋	49	11	21
23	3	31	6	24	4	52	7	25	2	47	8	22	3	11	9	23	2	9	10	22	1	46	11	22
24	4	32	6	25	5	52	7	26	3	47	8	23	4	10	9	24	3	6	10	23	2	44	11	23
25	5	33	6	26	6	52	7	27	4	46	8	21	5	8	9	25	4	4	10	24	3	41	11	24
26	6	34	6	27	7	53	7	28	5	45	8	25	6	6	9	26	5	2	10	25	4	38	11	25
27	7	35	6	28	8	53	7	29	6	45	8	26	7	4	9	27	5	59	10	26	5	35	11	26
28	8	36	6	29	9	53	8	0	7	44	8	27	8	3	9	28	6	56	10	27	6	32	11	27
29	9	37	7	0					8	43	8	28	9	1	9	29	7	54	10	28	7	30	11	28
30	10	38	7	1					9	42	8	29	9	59	9	29	8	51	10	29	8	27	11	29
31	11	39	7	2					10	41	9	0					9	48	11	0				

A Table shewing the Sun's true Place and Distance from his Apogee, for the second Year after Leap-year.

Days.	July.				August.				September.				October.				November.				December.			
	Sun's Place.		Sun's Anomaly.		Sun's Place.		Sun's Anomaly.		Sun's Place.		Sun's Anomaly.		Sun's Place.		Sun's Anomaly.		Sun's Place.		Sun's Anomaly.		Sun's Place.		Sun's Anomaly.	
	D.	M.	S.	D.	D.	M.	S.	D.	D.	M.	S.	D.	D.	M.	S.	D.	D.	M.	S.	D.	D.	M.	S.	D.
1	9 ♋	24	0	0	8	9	1	0	8 ♍	51	2	1	8 ♎	10	3	1	9 ♏	0	4	2	9 ♐	18	5	1
2	10	21	0	1	9	57	1	1	9	49	2	2	9	9	3	2	10	0	4	3	10	19	5	2
3	11	18	0	2	10	54	1	2	10	47	2	3	10	8	3	3	11	0	4	4	11	20	5	3
4	12	15	0	3	11	52	1	3	11	45	2	4	11	6	3	4	12	1	4	5	12	21	5	4
5	13	13	0	4	12	49	1	4	12	43	2	5	12	7	3	5	13	1	4	6	13	22	5	5
6	14	10	0	5	13	47	1	5	13	42	2	6	13	6	3	6	14	1	4	7	14	23	5	6
7	15	7	0	6	14	41	1	6	14	40	2	7	14	6	3	7	15	2	4	8	15	21	5	7
8	16	4	0	7	15	42	1	7	15	39	2	8	15	5	3	8	16	2	4	9	16	25	5	8
9	17	1	0	8	16	39	1	8	16	37	2	9	16	4	3	9	17	2	4	10	17	26	5	9
10	17	59	0	8	17	37	1	9	17	35	2	10	17	4	3	10	18	3	4	11	18	27	5	10
11	18	56	0	9	18	35	1	10	18	34	2	11	18	3	3	11	19	3	4	12	19	28	5	11
12	19	53	0	10	19	32	1	11	19	32	2	12	19	3	3	12	20	4	4	13	20	29	5	12
13	20	50	0	11	20	30	1	12	20	31	2	13	20	2	3	13	21	4	4	14	21	30	5	13
14	21	47	0	12	21	28	1	13	21	29	2	14	21	2	3	14	22	5	4	15	22	31	5	14
15	22	45	0	13	22	25	1	14	22	28	2	15	22	2	3	15	23	5	4	16	23	32	5	15
16	23	42	0	14	23	23	1	15	23	27	2	16	23	1	3	16	24	6	4	17	24	33	5	16
17	24	39	0	15	24	21	1	16	24	25	2	17	24	1	3	17	25	7	4	18	25	34	5	17
18	25	36	0	16	25	19	1	17	25	24	2	18	25	1	3	18	26	7	4	19	26	35	5	18
19	26	34	0	17	26	17	1	18	26	23	2	19	26	0	3	19	27	8	4	20	27	36	5	19
20	27	31	0	18	27	14	1	19	27	21	2	20	27	0	3	20	28	9	4	21	28	38	5	20
21	28	28	0	19	28	12	1	20	28	20	2	21	28	0	3	21	29	9	4	22	29	39	5	21
22	29	26	0	20	29	10	1	21	29	19	2	22	29	0	3	22	♐	10	4	23	♑	40	5	22
23	♌	23	0	21	♍	8	1	22	♎	18	2	23	♏	0	3	23	1	11	4	24	1	41	5	23
24	1	20	0	22	1	6	1	23	1	17	2	24	1	0	3	24	2	12	4	25	2	42	5	24
25	2	18	0	23	2	4	1	24	2	16	2	25	2	0	3	25	3	12	4	26	3	44	5	25
26	3	15	0	24	3	2	1	25	3	15	2	26	3	0	3	26	4	13	4	27	4	45	5	26
27	4	12	0	25	4	0	1	26	4	14	2	27	4	0	3	27	5	14	4	28	5	46	5	27
28	5	10	0	26	4	58	1	27	5	13	2	28	5	0	3	28	6	15	4	29	6	47	5	28
29	6	7	0	27	5	56	1	28	6	12	2	29	6	0	3	29	7	16	4	29	7	48	5	29
30	7	5	0	28	6	54	1	29	7	11	3	0	7	0	4	0	8	17	5	0	8	49	6	0
31	8	2	0	29	7	52	2	0					8	0	4	1					9	51	6	1

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The Bissextile, or Leap-year.

Days.	January.			February.			March.			April.			May.			June.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	3	59	XII	14	3	XII	12	32	XII	3	44	XI	56	48	XI	57	26
2		4	27		14	10		12	19		3	26		56	40		57	36
3		4	55		14	17		12	6		3	8		56	34		57	45
4		5	23		14	23		11	52		2	50		56	28		57	55
5		5	50		14	28		11	38		2	32		56	22		58	6
6	XII	6	17	XII	14	32	XII	11	24	XII	2	15	XI	56	17	XI	58	17
7		6	43		14	36		11	9		1	58		56	13		58	28
8		7	9		14	39		10	54		1	41		56	10		58	39
9		7	34		14	40		10	38		1	24		56	6		58	50
10		7	59		14	41		10	22		1	7		56	4		59	2
11	XII	8	23	XII	14	42	XII	10	6	XII	0	51	XI	56	2	XI	59	14
12		8	46		14	41		9	49		0	35		56	1		59	26
13		9	9		14	40		9	32		0	19		56	0		59	39
14		9	31		14	38		9	15		0	3		55	59		59	51
15		9	53		14	35		8	57	XI	59	49		55	59	XII	0	3
16	XII	10	14	XII	14	31	XII	8	40	XI	59	34	XI	56	0	XII	0	16
17		10	34		14	26		8	22		59	20		56	2		0	29
18		10	53		14	21		8	4		59	6		56	4		0	42
19		11	11		14	16		7	45		58	52		56	6		0	51
20		11	29		14	9		7	27		58	39		56	9		1	7
21	XII	11	46	XII	14	2	XII	7	8	XI	58	26	XI	56	13	XII	1	20
22		12	3		13	54		6	50		58	14		56	17		1	33
23		12	18		13	46		6	31		58	2		56	21		1	46
24		12	33		13	37		6	12		57	51		56	27		1	59
25		12	47		13	27		5	54		57	40		56	32		2	11
26	XII	13	0	XII	13	17	XII	5	35	XI	57	30	XI	56	39	XII	2	24
27		13	13		13	7		5	16		57	20		56	45		2	36
28		13	24		12	55		4	58		57	11		56	53		2	49
29		13	35		12	44		4	39		57	3		57	0		3	1
30		13	45					4	21		56	55		57	8		3	13
31		13	54					4	2					57	17			

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The Bissextile, or Leap-year.

Days.	July.			August.			September			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	3	25	XII	5	50	XI	59	33	XI	49	26	XI	43	47	XI	49	43
2		3	36		5	46		59	14		49	7		43	47		50	6
3		3	47		5	41		58	55		48	49		43	48		50	31
4		3	58		5	36		58	35		48	31		43	49		50	55
5		4	8		5	30		58	15		48	13		43	52		51	21
6	XII	4	18	XII	5	23	XI	57	5	XI	47	56	XI	43	55	XI	51	46
7		4	28		5	16		57	35		47	40		43	59		52	13
8		4	37		5	9		57	15		47	23		44	5		52	39
9		4	46		5	0		56	55		47	8		44	9		53	7
10		4	55		4	51		56	34		46	52		44	15		53	31
11	XII	5	2	XII	4	42	XI	56	13	XI	46	36	XI	44	23	XI	54	2
12		5	10		4	32		55	52		46	22		44	31		54	31
13		5	17		4	21		55	31		46	9		44	40		54	59
14		5	24		4	10		55	10		45	55		44	50		55	28
15		5	30		3	58		54	49		45	42		45	1		55	57
16	XII	5	35	XII	3	46	XI	54	28	XI	45	30	XI	45	12	XI	56	27
17		5	40		3	34		54	7		45	18		45	25		56	56
18		5	45		3	20		53	46		45	7		45	38		57	26
19		5	49		3	7		53	25		44	57		45	52		57	56
20		5	52		2	53		53	4		44	47		46	7		58	26
21	XII	5	55	XII	2	38	XI	52	44	XI	44	38	I	46	23	XI	58	56
22		5	57		2	23		52	23		44	30		46	40		59	26
23		5	59		2	8		52	2		14	22		46	57		59	57
24		6	0		1	52		51	42		44	15		47	15	XII	0	27
25		6	1		1	36		51	22		44	9		47	34		0	57
26	XII	6	1	XII	1	19	XI	51	2	XI	44	4	XI	47	54	XII	1	27
27		6	1		1	2		50	42		43	59		48	14		1	57
28		6	0		0	45		50	23		43	55		48	35		2	26
29		5	58		0	27		50	3		43	52		48	57		2	55
30		5	56		0	9		49	44		43	50		49	20		3	24
31		5	53	XII	59	51					43	48					3	53

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The first Year after Leap-year.

Days.	January.			February.			March.			April.			May.			June.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	4	21	XII	14	9	XII	12	36	XII	3	49	XI	56	50	XI	57	24
2		4	49		14	16		12	23		3	31		56	42		57	34
3		5	17		14	22		12	10		3	13		56	36		57	44
4		5	44		14	27		11	56		2	55		56	29		57	53
5		6	11		14	32		11	42		2	37		56	21		58	3
6	XII	6	37	XII	14	35	XII	11	28	XII	2	19	XI	56	19	XI	58	13
7		7	3		14	38		11	13		2	2		56	11		58	24
8		7	28		14	10		10	57		1	44		56	10		58	35
9		7	53		14	41		10	42		1	27		56	7		58	17
10		8	17		14	41		10	26		1	11		56	4		58	58
11	XII	8	40	XII	14	40	XII	10	9	XII	0	54	XI	56	2	XI	59	10
12		9	3		14	39		9	53		0	38		56	0		59	22
13		9	25		14	37		9	36		0	22		56	59		59	35
14		9	47		14	35		9	19		0	7		56	59		59	47
15		10	8		14	31		9	1	XI	59	52		56	59	XII	0	0
16	XII	10	28	XII	14	27	XII	8	44	XI	59	37	XI	56	0	XII	0	13
17		10	18		14	22		8	26		59	23		56	1		0	26
18		11	7		14	17		8	8		59	9		56	3		0	39
19		11	25		14	11		7	50		58	56		56	5		0	52
20		11	42		14	4		7	32		58	13		56	8		1	5
21	XII	11	59	XII	13	57	XII	7	13	XI	58	30	XI	56	12	XII	1	18
22		12	15		13	19		6	55		58	18		56	16		1	31
23		12	30		13	10		6	36		58	6		56	21		1	44
24		12	45		13	31		6	18		57	55		56	26		1	57
25		12	58		13	21		5	59		57	44		56	32		2	9
26	XII	13	11	XII	13	10	XII	5	41	XI	57	34	XII	56	38	XII	2	22
27		13	23		12	59		5	22		57	24		56	45		2	34
28		13	34		12	48		5	4		57	15		56	52		2	47
29		13	44					4	45		57	6		56	59		2	59
30		13	53					4	26		56	58		57	7		3	10
31		14	2					4	8					57	16			

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The first Year after Leap Year.

Days.	July.			August.			September.			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	3	22	XII	5	50	XI	59	37	XI	49	30	XI	43	47	XI	49	36
2		3	33		5	46		59	18		49	11		43	46		49	59
3		3	44		5	42		58	59		48	53		43	46		50	23
4		3	55		5	36		58	39		48	34		43	47		50	48
5		4	5		5	31		58	19		48	17		43	50		51	13
6	XII	4	15	XII	5	24	XI	57	59	XI	48	0	XI	43	53	XI	51	39
7		4	25		5	17		57	39		47	43		43	57		52	5
8		4	34		5	9		57	19		47	26		44	1		52	32
9		4	43		5	1		56	59		47	10		44	7		52	59
10		4	51		4	53		56	38		46	55		44	13		53	27
11	XII	5	0	XII	4	43	XI	56	18	XI	46	40	XI	44	20	XI	53	55
12		5	7		4	33		55	57		46	26		44	29		54	23
13		5	14		4	23		55	36		46	12		44	38		54	52
14		5	21		4	12		55	15		45	58		44	48		55	21
15		5	28		4	1		54	54		45	45		44	59		55	50
16	XII	5	33	XII	3	49	XI	54	34	XI	45	33	XI	45	10	XI	56	20
17		5	39		3	37		54	13		45	22		45	22		56	50
18		5	44		3	24		53	52		45	11		45	36		57	20
19		5	48		3	11		53	31		45	0		45	50		57	50
20		5	52		2	57		53	10		44	50		46	4		58	20
21	XII	5	55	XII	2	42	XI	52	49	XI	44	41	XI	46	20	XI	58	50
22		5	58		2	28		52	29		44	33		46	36		59	20
23		6	0		2	12		52	8		44	25		46	53		59	50
24		6	1		1	57		51	48		44	18		47	11	XII	0	20
25		6	2		1	41		51	27		44	11		47	30		0	49
26	XII	6	2	XII	1	24	XI	51	7	XI	44	6	XI	47	49	XII	1	19
27		6	2		1	7		50	47		44	1		48	9		1	49
28		6	1		0	50		50	27		43	56		48	30		2	18
29		5	59		0	32		50	8		43	53		48	51		2	47
30		5	57		0	14		49	49		43	50		49	13		3	16
31		5	54	XI	59	56					43	47					3	45

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The second Year after Leap-year.

Days.	January.			February.			March.			April.			May.			June.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	4	13	XII	14	6	XII	12	37	XII	3	52	XI	56	50	XI	57	21
2		4	41		14	13		12	25		3	34		56	43		57	30
3		5	9		14	19		12	12		3	16		56	38		57	40
4		5	36		14	25		11	58		2	58		56	30		57	50
5		6	3		14	29		11	44		2	40		56	24		58	0
6	XII	6	30	XII	14	3	XII	11	30	XII	2	22	XI	56	19	XI	58	11
7		6	56		14	56		11	15		2	5		56	14		58	22
8		7	21		14	58		11	0		1	48		56	10		58	33
9		7	46		14	19		10	15		1	31		56	7		58	45
10		8	10		14	11		10	29		1	14		56	4		58	56
11	XII	8	34	XII	14	11	XII	10	13	XII	0	58	XI	56	2	XI	59	8
12		8	58		14	10		9	56		0	42		56	1		59	21
13		9	20		14	[illegible]		9	40		0	26		56	0		59	33
14		9	42		14	56		9	23		0	11		55	59		59	45
15		10	3		14	33		9	6	XI	59	56		55	59		59	58
16	XII	10	24	XII	14	29	XII	8	48	XI	59	41	XI	56	0	XI	0	11
17		10	44		14	24		8	30		59	27		56	1		0	24
18		11	3		14	19		8	12		59	13		56	3		0	36
19		11	21		14	13		7	54		58	59		56	5		0	49
20		11	39		14	6		7	36		58	12		56	8		1	2
21	XII	11	55	XII	13	59	XII	7	18	XI	58	33	XI	56	11	XI	1	15
22		12	11		13	51		6	59		58	20		56	15		1	28
23		12	27		13	42		6	41		58	8		56	20		1	41
24		12	41		13	32		6	22		57	57		56	25		1	53
25		12	54		13	22		6	3		57	46		56	30		2	6
26	XII	13	7	XII	13	12	XII	5	44	XI	57	35	XI	56	36	XII	2	18
27		13	19		13	1		5	26		57	25		56	42		2	31
28		13	30		12	49		5	7		57	15		56	49		2	43
29		13	40					4	48		57	6		56	56		2	55
30		13	49					4	29		56	58		57	4		3	7
31		13	58					4	11					57	12			

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The second Year after Leap-year.

Days.	July.			August.			September			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	3	19	XII	5	51	XI	59	42	XI	49	35	XI	43	47	XI	49	31
2		3	30		5	48		59	23		49	16		43	46		49	54
3		3	41		5	43		59	4		48	58		43	47		50	18
4		3	52		5	38		58	45		48	40		43	49		50	44
5		4	0		5	33		58	25		48	22		43	51		51	8
6	XII	4	13	XII	5	27	XI	58	6	XI	48	5	XI	43	53	XI	51	34
7		4	23		5	20		57	46		47	48		43	57		52	0
8		4	33		5	13		57	26		47	32		44	2		52	27
9		4	42		5	5		57	5		47	16		44	7		52	54
10		4	51		4	56		56	45		47	0		44	13		53	21
11	XII	4	59	XII	4	17	XI	56	24	XI	46	45	XI	44	21	XI	53	49
12		5	7		4	38		56	4		46	31		44	28		54	17
13		5	11		4	28		55	43		46	17		44	37		54	46
14		5	21		4	17		55	22		46	3		44	46		55	15
15		5	28		4	5		55	1		45	50		44	57		55	43
16	XII	5	34	XII	3	54	XI	54	40	XI	45	37	XI	45	8	XI	56	13
17		5	39		3	41		54	19		45	25		45	20		56	42
18		5	44		3	28		53	58		45	14		45	32		57	12
19		5	48		3	15		53	37		45	3		45	46		57	42
20		5	52		3	1		53	16		44	53		46	1		58	12
21	XII	5	55	XII	2	47	XI	52	55	XI	44	44	XI	46	16	XI	58	42
22		5	57		2	32		52	34		44	35		46	32		59	12
23		5	59		2	16		52	13		44	27		46	49		59	42
24		6	1		2	1		51	53		44	19		47	6	XII	0	11
25		6	2		1	45		51	32		44	13		47	25		0	41
26	XII	6	2	XII	1	28	XI	51	12	XI	44	7	XI	47	44	XII	1	11
27		6	1		1	11		50	52		44	1		48	4		1	41
28		6	0		0	54		50	32		43	57		48	25		2	11
29		5	59		0	36		50	13		43	53		48	46		2	40
30		5	57		0	18		49	54		43	51		49	8		3	9
31		5	55		0	0					43	49					3	38

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The third Year after Leap-year.

Days.	January.			February.			March.			April.			May.			June.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	4	7	XII	14	1	XII	12	40	XII	3	57	XI	56	52	XI	57	10
2		4	35		14	12		12	28		3	38		56	45		57	29
3		5	3		14	18		12	15		3	20		56	38		57	38
4		5	30		14	24		12	2		3	2		56	31		57	48
5		5	58		14	29		11	48		2	45		56	25		57	58
6	XII	6	24	XII	14	33	XII	11	34	XII	2	27	XI	56	20	XI	58	9
7		6	50		14	30		11	19		2	9		56	16		58	19
8		7	16		14	38		10	4		1	52		56	12		58	30
9		7	41		14	40		10	49		1	35		56	8		58	42
10		8	5		14	41		10	33		1	18		56	5		58	53
11	XII	8	29	XII	14	43	XII	10	17	XII	1	2	XI	56	3	XI	59	5
12		8	52		14	40		10	0		0	45		56	1		59	17
13		9	15		14	38		9	43		0	29		55	59		59	29
14		9	37		14	36		9	26		0	14		55	59		59	41
15		9	58		14	33		9	9	XI	59	58		55	59		59	54
16	XII	10	18	XII	14	29	XII	8	51	XI	59	42	XI	55	59	XII	0	6
17		10	38		14	24		8	34		59	29		56	0		0	19
18		10	57		14	19		8	16		59	15		56	1		0	32
19		11	16		14	13		7	57		59	1		56	3		0	45
20		11	38		14	6		7	39		58	17		56	6		0	58
21	XII	11	50	XII	13	59	XII	7	21	XI	58	34	XI	56	9	XII	1	11
22		12	6		13	51		7	2		58	22		56	13		1	24
23		12	22		13	43		6	44		58	10		56	17		1	37
24		12	36		13	34		6	25		57	58		56	22		1	50
25		12	50		13	24		6	6		57	47		56	28		2	3
26	XII	13	3	XII	13	14	XII	5	48	XI	57	37	XI	56	34	XII	2	15
27		13	15		13	3		5	29		57	27		56	40		2	28
28		13	27		12	52		5	11		57	17		56	47		2	40
29		13	37					4	52		57	8		56	55		2	53
30		13	47					4	33		56	0		57	3		3	5
31		13	56					4	15					57	12			

A Table shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The third Year after Leap Year.

Days.	July.			August.			September.			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	3	17	XII	5	53	XI	59	47	XI	49	40	XI	43	48	XI	49	26
2		3	28		5	50		59	29		49	21		43	47		49	49
3		3	40		5	45		59	10		49	3		43	47		50	12
4		3	51		5	41		58	50		48	45		43	48		50	37
5		4	1		5	35		58	31		48	27		43	50		51	2
6	XII	4	11	XII	5	29	XI	58	11	XI	48	9	XI	43	52	XI	51	27
7		4	21		5	22		57	51		47	52		43	56		51	53
8		4	31		5	15		57	30		47	35		44	0		52	19
9		4	40		5	7		57	10		47	19		44	5		52	46
10		4	49		4	58		56	49		47	3		44	10		53	13
11	XII	4	57	XII	4	49	XI	56	29	XI	46	48	XI	44	17	XI	53	41
12		5	5		4	40		56	8		46	33		44	25		54	9
13		5	12		4	29		55	47		46	19		44	33		54	37
14		5	19		4	19		55	26		46	5		44	42		55	6
15		5	25		4	8		55	5		45	52		44	53		55	35
16	XII	5	31	XII	3	56	XI	54	44	XI	45	39	XI	45	4	XI	56	5
17		5	37		3	43		54	23		45	27		45	16		56	34
18		5	42		3	31		54	2		45	16		45	28		57	4
19		5	46		3	17		53	41		45	5		45	42		57	34
20		5	50		3	4		53	20		44	55		45	56		58	4
21	XII	5	53	XII	2	50	XI	52	59	XI	44	45	XI	46	12	XI	58	34
22		5	56		2	35		52	39		44	37		46	28		59	4
23		5	59		2	20		52	18		44	29		46	44		59	35
24		6	0		2	5		51	58		44	21		47	2	XII	0	5
25		6	1		1	49		51	37		44	14		47	21		0	35
26	XII	6	2	XII	1	33	XI	51	17	XI	44	8	XI	47	40	XII	1	5
27		6	2		1	16		50	57		44	3		47	59		1	35
28		6	2		0	59		50	38		43	59		48	20		2	4
29		6	1		0	41		50	18		43	55		48	41		2	34
30		5	59		0	24		49	59		43	52		49	3		3	3
31		5	55		0	6					43	49					3	32

*** Observe, by a good meridian line, or by a transit instrument properly fixed, the moment when the Sun's centre is on the meridian; and set the clock to the time marked in the preceding table for that day of the year;—then, if the clock goes true, it will point to the time shewn in the table every day afterwards at the instant when it is noon by the Sun, which is when his centre is on the meridian.—Thus, in the first year after leap-year, on the 20th of October, when it is noon by the Sun, the true equal time by the clock is only 44 minutes 50 seconds past XI; and on the last day of December (in that year) it should be 3 minutes 45 seconds past XII by the clock when the Sun's centre is on the meridian.

The following table was made from the preceding one, and is of the common form of a table of the equation of time, shewing how much a clock regulated to keep mean or equal time, is before or behind the apparent or solar time, every day of the year.

A

TABLE

OF THE

EQUATION OF TIME,

SHEWING

HOW MUCH A CLOCK SHOULD BE FASTER OR SLOWER THAN THE SUN, AT THE NOON OF EVERY DAY IN THE YEAR, BOTH IN LEAP-YEARS AND COMMON YEARS.



[The Asterisks in the Table shew where the Equation changes to slow or fast.]

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The Bissextile or Leap-year.

Days.	January.		February.		March.		April.		May.		June.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
	Clock faster.		Clock faster.		Clock faster.		Clock faster.		Clock slower.		Clock slower.	
1	3	59	14	3	12	32	3	44	3	13	2	34
2	4	27	14	10	12	19	3	26	3	20	2	24
3	4	55	14	17	12	6	3	8	3	26	2	15
4	5	23	14	23	11	52	2	50	3	32	2	5
5	5	50	14	28	11	38	2	32	3	38	1	54
6	6	17	14	32	11	24	2	15	3	42	1	43
7	6	43	14	36	11	9	1	58	3	47	1	32
8	7	9	14	39	10	54	1	41	3	50	1	21
9	7	34	14	40	10	38	1	24	3	53	1	10
10	7	59	14	41	10	22	1	7	3	56	0	58
11	8	23	14	42	10	6	0	51	3	58	0	46
12	8	46	14	41	9	49	0	[illegible]	3	59	0	34
13	9	9	14	40	9	32	0	19	4	0	0	21
14	9	31	14	37	9	15	0	4	4	1	0	9
15	9	53	14	34	8	57	0	*11	4	1	0	*3
16	10	14	14	11	8	40	0	26	4	0	0	16
							Clock slower.				Clock faster.	
17	10	34	14	26	8	22	0	40	3	58	0	29
18	10	53	14	21	8	4	0	54	3	56	0	42
19	11	11	14	16	7	45	1	8	3	54	0	54
20	11	29	14	9	7	27	1	21	3	51	1	7
21	11	46	14	2	7	8	1	34	3	47	1	20
22	12	3	13	54	6	50	1	46	3	43	1	33
23	12	18	13	46	6	31	1	58	3	39	1	46
24	12	33	13	37	6	12	2	2	3	33	1	59
25	12	47	13	27	5	54	2	20	3	28	2	11
26	13	0	13	17	5	35	2	30	3	21	2	24
27	13	13	13	6	5	16	2	40	3	14	2	36
28	13	24	12	55	4	58	2	49	3	7	2	49
29	13	35	12	44	4	39	2	57	3	0	3	1
30	13	45			4	21	3	5	2	51	3	13
31	13	54			4	2			2	43		

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The Bissextile, or Leap-year.

Days.	July.		August.		September.		October.		November.		December.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
	Clock faster.		Clock faster.		Clock slower.		Clock slower.		Clock slower.		Clock slower. / faster.	
1	3	25	5	50	0	27	10	34	16	13	10	17
2	3	36	5	46	0	46	10	53	16	13	9	54
3	3	47	5	41	1	5	11	11	16	12	9	29
4	3	58	5	36	1	25	11	29	16	11	9	5
5	4	8	5	30	1	14	11	47	16	8	8	39
6	4	18	5	23	2	4	12	4	16	5	8	17
7	4	28	5	16	2	24	12	20	16	1	7	47
8	4	37	5	9	2	15	12	37	15	57	7	21
9	4	46	5	0	[illegible]	5	12	53	15	51	6	54
10	4	55	4	51	3	20	13	8	15	44	6	26
11	5	2	4	12	3	47	13	23	15	37	5	58
12	5	10	4	[illegible]	4	8	13	37	15	29	5	30
13	5	17	4	[illegible]	4	29	13	51	15	20	5	1
14	5	24	4	10	4	50	14	5	15	10	4	32
15	5	30	3	[illegible]	5	11	14	18	14	59	4	3
16	5	65	3	46	5	32	14	30	14	48	3	33
17	5	40	3	31	5	53	14	42	14	35	3	4
18	5	45	3	20	6	14	14	53	14	22	2	34
19	5	49	3	7	6	35	15	3	14	8	2	4
20	5	52	2	53	6	56	15	13	13	53	1	34
21	5	55	2	38	7	16	15	22	13	37	1	4
22	5	57	2	23	7	37	15	30	13	20	0	34
23	5	59	2	8	7	58	15	38	13	3	0	3
24	6	0	1	52	8	18	15	45	12	45	0	*27
25	6	1	1	36	8	38	15	51	12	26	0	57
26	6	1	1	19	8	58	15	56	12	6	1	27
27	6	0	1	2	9	18	16	1	11	46	1	57
28	5	59	0	45	9	37	16	5	11	25	2	26
29	5	58	0	27	9	57	16	8	11	3	2	55
30	5	56	0	9	10	16	16	13	10	40	3	4
31	5	53	3	*9			16	12			3	53

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The First Year after Leap-year.

Days.	January.		February.		March.		April.		May.		June.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
1	4	21	14	9	12	36	3	49	3	10	2	36
2	4	49	14	16	12	23	3	31	3	18	2	27
3	5	17	14	22	12	10	3	13	3	24	2	17
4	5	44	14	27	11	56	2	55	3	31	2	7
5	6	11	14	32	11	42	2	37	3	36	1	57
	Clock		Clock		Clock		Clock		Clock		Clock	
6	6	37	14	35	11	28	2	19	3	41	1	47
7	7	3	14	38	11	13	2	2	3	46	1	36
8	7	28	14	40	10	57	1	44	3	50	1	25
9	7	53	14	41	10	42	1	27	3	53	1	13
10	8	17	14	41	10	26	1	11	3	56	1	2
	faster.		faster.		faster.		faster.		slower.		slower.	
11	8	40	14	40	10	9	0	54	3	58	0	50
12	9	3	14	39	9	53	0	39	4	0	0	38
13	9	25	14	37	9	36	0	22	4	1	0	25
14	9	47	14	35	9	19	0	7	4	1	0	13
15	10	8	14	31	9	1	0	*8	4	1	0	*0
16	10	28	14	27	8	44	0	23	4	0	0	13
17	10	48	14	23	8	26	0	37	3	59	0	26
18	11	7	14	17	8	8	0	51	3	57	0	39
19	11	25	14	11	7	50	1	4	3	54	0	52
20	11	42	14	4	7	32	1	17	3	51	1	5
							Clock				Clock	
21	11	59	13	57	7	13	1	30	3	48	1	18
22	12	15	13	49	6	55	1	42	3	44	1	31
23	12	30	13	40	6	37	1	54	3	39	1	44
24	12	45	13	31	6	18	2	5	3	34	1	57
25	12	58	13	21	5	59	2	16	3	28	2	9
							slower.				faster.	
26	13	11	13	10	5	41	2	26	3	22	2	22
27	13	23	12	59	5	22	2	36	3	15	2	34
28	13	34	12	48	5	4	2	45	3	8	2	47
29	13	44			4	45	2	54	3	1	2	59
30	13	53			4	26	3	2	2	53	3	10
31	14	2			4	8			2	44		

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The FIRST Year after Leap-year.

Days.	July.		August.		September.		October.		November.		December.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	
—	Clock faster.		Clock faster.		Clock slower.		Clock slower.		Clock slower.		Clock slower.	
1	3	22	5	50	0	23	10	30	16	13	10	24
2	3	33	5	46	0	42	10	49	16	14	10	1
3	3	44	5	42	1	1	11	7	16	13	9	37
4	3	55	5	36	1	21	11	26	16	12	9	12
5	4	5	5	31	1	41	11	43	16	10	8	47
6	4	15	5	24	2	1	12	0	16	7	8	21
7	4	25	5	17	2	21	12	27	16	3	7	55
8	4	34	5	9	2	41	12	34	15	59	7	28
9	4	43	5	1	3	1	12	50	15	53	7	1
10	4	51	4	53	3	22	13	5	15	47	6	33
11	5	0	4	43	3	42	13	20	15	39	6	5
12	5	7	4	34	4	3	13	34	15	31	5	37
13	5	14	4	23	4	24	13	48	15	22	5	8
14	5	21	4	12	4	45	14	2	15	12	4	39
15	5	28	4	1	5	6	14	14	15	2	4	10
16	5	33	3	49	5	26	14	27	14	50	3	40
17	5	39	3	37	5	47	14	38	14	37	3	10
18	5	44	3	24	6	8	14	49	14	24	2	40
19	5	48	3	11	6	29	15	0	14	10	2	10
20	5	52	2	57	6	50	15	10	13	56	1	40
21	5	55	2	42	7	11	15	19	13	40	1	10
22	5	58	2	27	7	31	15	27	13	24	0'	40
23	6	0	2	12	7	52	15	35	13	7	0	10
24	6	1	1	57	8	12	15	42	12	49	0	*20
25	6	2	1	41	8	33	15	49	12	30	0	49
—											Faster.	
26	6	2	1	24	8	53	15	54	12	11	1	19
27	6	2	1	7	9	13	16	0	11	51	1	49
28	6	1	0	50	9	33	16	4	11	30	2	18
29	5	59	0	32	9	52	16	7	11	9	2	47
30	5	57	0	14	10	11	16	10	10	47	3	16
31	5	54	0	*4			16	12			3	45

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every day of the Year, at Noon.

The Second Year after Leap-year.

Days.	January.		February.		March.		April.		May.		June.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
1	4	13	14	6	12	37	3	52	3	10	2	39
2	4	41	14	13	12	25	3	34	3	17	2	30
3	5 Clock	9	14 Clock	19	12 Clock	12	3 Clock	16	3 Clock	24	2 Clock	20
4	5	36	14	25	11	58	2	58	3	30	2	10
5	6	3	14	29	11	44	2	40	3	36	2	0
6	6	30	14	33	11	30	2	22	3	41	1	49
7	6	56	14	36	11	15	2	5	3	46	1	38
8	7 faster.	21	14 faster.	38	11 faster.	0	1 faster.	48	3 slower.	49	1 slower.	27
9	7	46	14	40	10	45	1	31	3	53	1	15
10	8	10	14	41	10	29	1	14	3	56	1	4
11	8	34	14	41	10	13	0	58	3	58	0	52
12	8	58	14	40	9	56	0	42	3	59	0	39
13	9	20	14	38	9	40	0	26	4	0	0	27
14	9	42	14	36	9	23	0	11	4	1	0	15
15	10	3	14	33	9	6	0	*4	4	1	0	2
16	10	24	14	29	8	48	0	19	4	0	0	*11
17	10	44	14	24	8	30	0	33	3	59	0	24
18	11	3	14	19	8	12	0 Clock	47	3	57	0 Clock	36
19	11	21	14	13	7	54	1	1	3	55	0	49
20	11	39	14	6	7	36	1	14	3	52	1	2
21	11	55	13	59	7	18	1	27	3	49	1	15
22	12	11	13	51	6	59	1	40	3	45	1	28
23	12	27	13	42	6	41	1 slower.	52	3	40	1 faster.	41
24	12	41	13	32	6	22	2	3	3	35	1	53
25	12	54	13	22	6	3	2	14	3	30	2	6
26	13	7	13	12	5	44	2	25	3	24	2	18
27	13	19	13	1	5	26	2	35	3	18	2	31
28	13	30	12	49	5	7	2	45	3	11	2	43
29	13	40			4	48	2	54	3	4	2	55
30	13	49			4	29	3	2	2	56	3	7
31	13	58			4	11			3	48		

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every day of the Year, at Noon.

The SECOND Year after Leap-year.

Days.	July. Clock faster.		August. Clock faster.		September. Clock slower.		October. Clock slower.		November. Clock slower.		December. Clock slower.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
1	3	19	5	51	0	18	10	25	16	13	10	29
2	3	30	5	48	0	37	10	44	16	13	10	6
3	3	41	5	43	0	56	11	2	16	12	9	42
4	3	52	5	38	1	15	11	20	16	11	9	17
5	4	3	5	33	1	35	11	38	16	9	8	52
6	4	13	5	27	1	54	11	55	16	7	8	26
7	4	23	5	20	2	14	12	12	16	3	8	0
8	4	33	5	13	2	34	12	28	15	58	7	35
9	4	42	5	5	2	55	12	44	15	53	7	6
10	4	51	4	56	3	15	13	0	15	47	6	39
11	4	59	4	47	3	36	13	15	15	40	6	11
12	5	7	4	38	3	56	13	29	15	32	5	43
13	5	14	4	28	4	17	13	43	15	23	5	14
14	5	21	4	17	4	38	13	57	15	13	4	45
15	5	28	4	5	4	59	14	10	15	3	4	26
16	5	34	3	54	5	20	14	23	14	52	3	47
17	5	39	3	41	5	41	14	35	14	40	3	18
18	5	44	3	28	6	2	14	46	14	28	2	48
19	5	48	3	15	6	23	14	57	14	14	2	18
20	5	52	3	1	6	44	15	7	13	59	1	48
21	5	55	2	47	7	5	15	16	13	44	1	18
22	5	57	2	32	7	26	15	25	13	28	0	48
23	5	59	2	16	7	47	15	33	13	11	0	18
24	6	1	2	1	8	7	15	41	12	54	0	*11
25	6	2	1	45	8	28	15	47	12	35	0	41
26	6	2	1	28	8	48	15	53	12	16	1	11
27	6	2	1	11	9	8	15	59	11	56	1	41 faster.
28	6	1	0	54	9	28	16	3	11	35	2	11
29	5	59	0	36	9	47	16	7	11	14	2	40
30	5	57	0	18	10	6	16	9	10	52	3	9
31	5	55	0	*0			16	11			3	38

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every day of the Year, at Noon.

The Third Year after Leap-year.

Days.	January. M.	January. S.	February. M.	February. S.	March. M.	March. S.	April. M.	April. S.	May. M.	May. S.	June. M.	June. S.
	Clock faster.		Clock faster.		Clock faster.		Clock faster.		Clock slower.		Clock slower.	
1	4	7	14	5	12	40	3	57	3	8	2	41
2	4	35	14	12	12	28	3	38	3	15	2	31
3	5	3	14	18	12	15	3	20	3	22	2	22
4	5	30	14	24	12	2	3	2	3	29	2	12
5	5	58	14	29	11	48	2	45	3	34	2	2
6	6	24	14	33	11	34	2	27	3	40	1	51
7	6	50	14	36	11	19	2	9	3	44	1	41
8	7	16	14	38	11	4	1	52	3	48	1	30
9	7	41	14	40	10	49	1	35	3	52	1	18
10	8	5	14	41	10	33	1	8	3	55	1	7
11	8	29	14	41	10	17	1	2	3	57	0	55
12	8	52	14	40	10	0	0	45	3	59	0	43
13	9	15	14	38	9	43	0	29	4	1	0	31
14	9	37	14	36	9	26	0	14	4	1	0	19
15	9	58	14	33	9	9	0	*2	4	2	0	6
							Clock slower.				Clock faster.	
16	10	18	14	29	8	51	0	17	4	1	0	*6
17	10	38	14	24	8	34	0	31	4	0	0	19
18	10	57	14	19	8	16	0	45	3	59	0	32
19	11	15	14	13	7	57	0	59	3	57	0	45
20	11	33	14	6	7	39	1	13	3	54	0	58
21	11	50	13	59	7	21	1	26	3	51	1	11
22	12	6	13	51	7	2	1	38	3	47	1	24
23	12	22	13	43	6	44	1	50	3	43	1	37
24	12	36	13	34	6	25	2	2	3	38	1	50
25	12	50	13	24	6	6	2	13	3	32	2	3
26	13	3	13	14	5	48	2	23	3	26	2	15
27	13	15	13	3	5	29	2	33	3	20	2	28
28	13	27	12	52	5	11	2	43	3	13	2	40
29	13	37			4	52	2	52	3	5	2	53
30	13	47			4	33	3	0	2	58	3	5
31	13	56			4	15			2	49		

A Table of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The Third Year after Leap-Year.

Days.	July. (Clock faster.)		August. (Clock faster.)		September. (Clock slower.)		October. (Clock slower.)		November. (Clock slower.)		December. (Clock slower.)	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
1	3	17	5	53	0	*13	10	20	16	12	10	34
2	3	28	5	50	0	31	10	39	16	13	10	11
3	3	40	5	45	0	50	10	57	16	13	9	48
4	3	51	5	41	1	10	11	16	16	12	9	23
5	4	1	5	35	1	29	11	33	16	10	8	58
6	4	11	5	29	1	49	11	51	16	8	8	33
7	4	21	5	22	2	9	12	8	16	4	8	7
8	4	31	5	15	2	30	12	25	16	0	7	41
9	4	40	5	7	2	50	12	41	15	55	7	14
10	4	49	4	58	3	11	12	57	15	50	6	47
11	4	57	4	49	3	31	13	12	15	43	6	19
12	5	5	4	40	3	52	13	27	15	35	5	51
13	5	12	4	29	4	13	13	41	15	27	5	23
14	5	19	4	19	4	34	13	55	15	18	4	54
15	5	25	4	8	4	55	14	8	15	7	4	25
16	5	31	3	56	5	16	14	21	14	56	3	55
17	5	37	3	43	5	37	14	33	14	44	3	26
18	5	42	3	31	5	58	14	44	14	32	2	56
19	5	46	3	17	6	19	14	55	14	18	2	26
20	5	50	3	4	6	40	15	5	14	4	1	56
21	5	53	2	50	7	1	15	15	13	48	1	26
22	5	56	2	35	7	21	15	23	13	32	0	56
23	5	59	2	20	7	42	15	32	13	16	0	25
24	6	0	2	5	8	2	15	39	12	58	0	*5
25	6	1	1	49	8	23	15	46	12	39	0	35
26	6	*2	1	33	8	43	15	52	12	20	1	5
27	6	2	1	16	9	3	15	57	12	1	1	35
28	6	2	0	59	9	23	16	1	11	40	2	4
29	6	1	0	41	9	42	16	5	11	19	2	34
30	5	59	0	24	10	1	16	8	10	57	3	3
31	5	56	0	6			16	11			3	32

(December, 26–30: Faster.)

A concise Equation Table, adapted to the second Year after Leap-Year, and within a Minute of the Truth for every Year; shewing, to the nearest full Minute, how much a Clock should be faster or slower than the Sun By Mr. Smeaton.

Months.	Days.	Equation in Minutes		Months.	Days.	Equation in Minutes.		Months.	Days.	Equation in Minutes.		Months.	Days.	Equation in Minutes.	
Jan.	1	4	Clock faster than the Sun.	April	1	4	Clock faster.	Aug	9	5	Clock faster.	Oct	27	16	Clock slower than the Sun.
	3	5			4	3			15	4		Nov.	15	15	
	5	6			7	2			20	3			20	14	
	7	7			11	1			24	2			24	13	
	9	8			15	0			28	1			27	12	
	12	9			*				31	0			30	11	
	15	10			19	1	Clock slower.		*			Dec.	2	10	
	18	11			24	2		Sept.	3	1	Clock slower than the Sun.		5	9	
	21	12			30	3			6	2			7	8	
	25	13		May	13	4			9	3			9	7	
	31	14			29	3			12	4			11	6	
Feb.	10	15		June	5	2			15	5			13	5	
	21	14			10	1			18	6			16	4	
	27	13			15	0			21	7			18	3	
Mar.	4	12			*				24	8			20	2	
	8	11			20	1	Clock faster.		27	9			22	1	
	12	10			25	2			30	10			24	0	
	15	9			29	3		Oct.	3	11			*		
	19	8		July	5	4			6	12			26	1	Faster.
	22	7			11	5			10	13			28	2	
	25	6			28	6			14	14			30	3	
	28	5							19	15					

This table is near enough for regulating common clocks and watches. It may be easily copied by the pen, and being doubled, may be put into a pocket-book.

CHAP. XV.

THE MOON'S SURFACE MOUNTAINOUS—HER PHASES DESCRIBED—HER PATH, AND THE PATHS OF JUPITER'S MOONS DELINEATED—THE PROPORTIONS OF THE DIAMETERS OF THEIR ORBITS, AND THOSE OF SATURN'S MOONS, TO EACH OTHER; AND TO THE DIAMETER OF THE SUN.

252. By looking at the Moon with an ordinary telescope, we perceive that her surface is diversified with long tracts of prodigious high mountains and deep cavities. Some of her mountains, by comparing their height with her diameter (which is 2180 miles), are found to be three times higher than the highest hills on our Earth.[1] This ruggedness of the Moon's surface is of great use to us, by reflecting the Sun's light to all sides; for if the Moon were smooth and polished like a looking-glass, or covered with water, she could never distribute the Sun's light all around; only in some positions she would shew us his image, no bigger than a point, but with such a lustre as would be hurtful to our eyes.

The Moon's surface mountainous.

253. The Moon's surface being so uneven, many have wondered why her edge does not appear jagged, as well as the curve bounding the light and dark places. But if we consider, that what we call the edge of the Moon's disc is not a single line set round with mountains, in which case it would appear irregularly indented, but a large zone having many mountains lying behind one another from the observer's eye, we shall find that the mountains in some rows will be opposite to the vales in others; and so fill up the inequalities as to make her appear quite round: just as when one looks at an orange, although its roughness be very discernible on the side next the eye, especially if the Sun or a candle

Why no hills appear on her edge.

[1] It appears from the observations of Schroeter, that the height of *Leibnitz*, one of the highest mountains in the Moon, does not exceed 24,700 feet. *Chimboraço*, the highest mountain on our Earth, is fully 19,200 feet; so that the highest lunar mountains are scarcely 1¼ times higher than the highest on our globe. See the supplementary chapter on Selerography.—*Ed.*

shines obliquely on that side, yet the line terminating the visible part still appears smooth and even.

The Moon has no twilight.

254. As the Sun can only enlighten that half of the Earth which is at any moment turned towards him, and being withdrawn from the opposite half, leaves it in darkness; so he likewise doth to the Moon: only with this difference, that the Earth, being surrounded by an atmosphere, and the Moon having none (See p. 19, Note 2), we have twilight after the Sun sets; but the lunar inhabitants have an immediate transition from the brightest sun-shine to the blackest darkness, § 177. For, let *t r k s w* be the Earth,

Plate VII. Fig. 1.

and *A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, the Moon in eight different parts of her orbit; as the Earth turns round its axis, from west to east, when any place comes to *t*, the twilight begins there, and when it revolves from thence to *r*, the Sun *S* rises; when the place comes to *s* the Sun sets, and when it comes to *w* the twilight ends. But as the Moon turns round her axis, which is only once a month, the moment that any point of her surface comes to *r* (See the Moon at *G*), the Sun rises there without any previous warning by twilight;[2] and when the same point comes to *s* the Sun sets, and that point goes into darkness as black as at midnight.

The Moon's phases.

255. The Moon being an opaque spherical body (for her hills take off no more from her roundness than the inequalities on the surface of an orange take off from its roundness), we can only see that part of the enlightened half of her which is towards the Earth. And, therefore, when the Moon is at *A*, in conjunction with the Sun *S*, her dark half is towards the Earth, and she disappears as at *a*, there being no light on that half to render it visible. When she comes to her first octant at *B*, or has gone an eighth part of her orbit from her conjunction, a quarter of her enlightened side is seen towards the Earth, and she appears horned, as at *b*.

[2] If the Moon had a twilight, it is evident that the portion of the obscure part of her disc which is immediately contiguous to the enlightened part, should be lighter than any other portion of the dark hemisphere; and since the twilight is always greater at the poles than at the equator, this faint light, bordering on the line which terminates the visible hemisphere, should be more perceptible at the poles than at the equator. M. Schroeter has actually discovered a faint border of grey light at the cusps of the Moon, and has thus proved the existence of a twilight, and consequently of an atmosphere in the Moon. See the supplementary chapter on Selenography.—*Ed.*

When she has gone a quarter of her orbit from between the Earth and Sun to *C*, she shews us one half of her enlightened side, as at *c*, and we say she is a quarter old. At *D* she is in her second octant, and by shewing us more of her enlightened side she appears gibbous, as at *d*. At *E* her whole enlightened side is towards the Earth, and therefore she appears round, as at *e*, when we say, it is full Moon. In her third octant at *F*, part of her dark side being towards the Earth, she again appears gibbous, and is on the decrease, as at *f*. At *G* we just see one half of her enlightened side, and she appears half decreased, or in her third quarter, as at *g*. At *H* we only see a quarter of her enlightened side, being in her fourth octant, where she appears horned, as at *h*. And at *A*, having completed her course from the Sun to the Sun again, she disappears; and we say it is new Moon. Thus, in going from *A* to *E*, the Moon seems continually to increase; and in going from *E* to *A*, to decrease in the same proportion; having like phases at equal distances from *A* to *E*, but as seen from the Sun *S*, she is always full.

256. The Moon appears not perfectly round when she is full in the highest or lowest part of her orbit, because we have not a full view of her enlightened side at that time. When full in the highest part of her orbit, a small deficiency appears on her lower edge; and the contrary when full in the lowest part of her orbit. The Moon's disc not always quite round when full.

257. It is plain by the figure, that when the Moon changes to the Earth, the Earth appears full to the Moon; and *vice versa*. For when the Moon is at *A*, *new* to the Earth, the whole enlightened side of the Earth is towards the Moon; and when the Moon is at *E*, *full* to the Earth, its dark side is towards her. Hence a *new Moon* answers to a *full Earth*, and a *full Moon* to a *new Earth*. The *quarters* are also reversed to each other. The phases of the Earth and Moon contrary.

258. Between the third quarter and change, the Moon is frequently visible in the forenoon even when the Sun shines; and then she affords us an opportunity of seeing a very agreeable appearance, wherever we find a globular stone above the level of the eye, as suppose on the top of a gate. For, if the Sun shines on the stone, and we place ourselves so that the upper part of the stone may just seem to touch the point of the Moon's lowermost horn, we shall An agreeable phenomenon.

then see the enlightened part of the stone exactly of the same shape with the Moon, horned as she is, and inclined the same way to the horizon. The reason is plain; for the Sun enlightens the stone the same way as he does the Moon; and both being globes, when we put ourselves into the above situation, the Moon and stone have the same position to our eyes; and, therefore, we must see as much of the illuminated part of the one as of the other.

The nonagesimal degree, what.

259. The position of the Moon's cusps, or a right line touching the points of her horns, is very differently inclined to the horizon at different hours of the same days of her age. Sometimes she stands, as it were, upright on her lower horn, and then such a line is perpendicular to the horizon; when this happens, she is in what the astronomers call *the Nonagesimal Degree*; which is the highest point of the ecliptic above the horizon at that time, and is 90° from both sides of the horizon where it is then cut by the ecliptic. But this never happens when the Moon is on the meridian, except when she is at the very beginning of Cancer or Capricorn.

How the inclination of the ecliptic may be found by the position of the Moon's horns

260. The inclination of that part of the ecliptic to the horizon in which the Moon is at any time when horned, may be known by the position of her horns; for a right line touching their points is perpendicular to the ecliptic. And as the angle which the Moon's orbit makes with the ecliptic can never raise her above, nor depress her below the ecliptic, more than 2 minutes of a degree, as seen from the Sun; it can have no sensible effect upon the position of her horns. Therefore, if a quadrant be held up, so that one of its edges may seem to touch the Moon's horns, the graduated side being kept towards the eye, and as far from the eye as it can be conveniently held, the arc between the plumb-line and that edge of the quadrant which seems to touch the Moon's horns will shew the inclination of that part of the ecliptic to the horizon. And the arc between the other edge of the quadrant and plumb-line will shew the inclination of a line, touching the Moon's horns, to the horizon.

Plate VII. Fig. 1. Why the Moon appears as big as the Sun.

261. The Moon generally appears as large as the Sun; for the angle $v\ k\ A$, under which the Moon is seen from the Earth, is the same with the angle $L\ k\ M$, under which the Sun is seen from it. And therefore the Moon may hide the

Sun's whole disc from us, as she sometimes does in solar eclipses. The reason why she does not eclipse the Sun at every change, will be explained afterwards. If the Moon were farther from the Earth, as at *a*, she would never hide the whole of the Sun from us; for then she would appear under the angle *N k O*, eclipsing only that part of the Sun which lies between *N* and *O*: were she still further from the Earth, as at *X*, she would appear under the small angle *T k W*, like a spot on the Sun, hiding only the part *T W* from our sight.

262. That the Moon turns round her axis in the time that she goes round her orbit, is quite demonstrable; for a spectator at rest, without the periphery of the Moon's orbit, would see all her sides turned regularly towards him in that time. She turns round her axis from any star to the same star again in 27 days 8 hours; from the Sun to the Sun again in $29\frac{1}{2}$ days: the former is the length of her sydereal day, and the latter the length of her solar day. A body moving round the Sun would have a solar day in every revolution, without turning on its axis; the same as if it had kept all the while at rest, and the Sun moved round it: but without turning round its axis it could never have one sydereal day, because it would always keep the same side towards any given star.

A proof of the Moon's turning round her axis.

263. If the Earth had no annual motion, the Moon would go round it so as to complete a lunation, a sydereal, and a solar day, all in the same time. But, because the Earth goes forward in its orbit, while the Moon goes round the Earth in her orbit, the Moon must go as much more than round her orbit from change to change in completing a solar day, as the Earth has gone forward in its orbit during that time, *i. e.* almost a twelfth part of a circle.

Her periodical and synodical revolution.

264. The Moon's periodical and synodical revolution may be familiarly represented by the motions of the hour and minute-hands of a watch round its dial-plate, which is divided into 12 equal parts or hours, as the ecliptic is divided into 12 signs, and the year into 12 months. Let us suppose these 12 hours to be 12 signs, the hour-hand the Sun, and the minute-hand the Moon, then the former will go round once in a year, and the latter once in a month: but the Moon, or minute-hand, must go more than round from any point of

Familiarly represented.

the circle where it was last conjoined with the Sun, or hour-hand, to overtake it again; for, the hour-hand being in motion, can never be overtaken by the minute-hand at that point from which they started at their last conjunction. The first column of the following table, shews the number of conjunctions which the hour and minute-hand make whilst the hour-hand goes once round the dial-plate; and the other columns shew the times when the two hands meet at each conjunction. Thus, suppose the two hands to be in conjunction at XII, as they always are; then, at the first following conjunction it is 5 minutes 27 seconds 16 thirds 21 fourths $49\frac{1}{11}$ fifths past I, where they meet; at the second conjunction it is 10 minutes 54 seconds 32 thirds 43 fourths $38\frac{2}{11}$ fifths past II; and so on. This, though an easy illustration of the motions of the Sun and Moon, is not precise as to the times of their conjunctions; because, while the Sun goes round the ecliptic, the Moon makes $12\frac{3}{7}$ conjunctions with him; but the minute-hand of a watch or clock makes only 11 conjunctions with the hour-hand in one period round the dial-plate. But if, instead of the common wheel-work at the back of the dial-plate, the axis of the minute-hand had a pinion of 6 leaves turning a wheel of 74, and this last turning the hour-hand, in every revolution it makes round the dial-plate the minute-hand would make $12\frac{3}{7}$ conjunctions with it, and so would be a pretty device for shewing the motions of the Sun and Moon; especially, as the slowest moving hand might have a little sun fixed on its point, and the quickest a little moon.

A Table shewing the times that the hour and minute hands of a watch are in conjunction.

Conj.	H.	M.	S.	‴	⁗	v pts.
1	I	5	27	16	21	$49\frac{1}{11}$
2	II	10	54	32	43	$38\frac{2}{11}$
3	III	16	21	49	5	$27\frac{3}{11}$
4	IIII	21	49	5	27	$16\frac{4}{11}$
5	V	27	10	21	49	$5\frac{5}{11}$
6	VI	32	43	38	10	$54\frac{6}{11}$
7	VII	38	10	54	32	$43\frac{7}{11}$
8	VIII	43	38	10	54	$32\frac{8}{11}$
9	IX	49	5	27	16	$21\frac{9}{11}$
10	X	54	32	43	38	$10\frac{10}{11}$
11	XII	0	0	0	0	0

*265. If the Earth had no annual motion, the Moon's motion round the Earth, and its track in open space, would be always the same.[*] But as the Earth and Moon move round the Sun, the Moon's real path in the heavens is very different from her visible path round the Earth: the latter being in a progressive circle, and the former in a curve of different degrees of concavity, which would always be the same in the same parts of the heavens, if the Moon performed a complete number of lunations in a year without any fraction.

The Moon's motion thro' open space described.

266. Let a nail in the end of the axle of a chariot wheel represent the Earth, and a pin in the nave the Moon; if the body of the chariot be propped up so as to keep that wheel from touching the ground, and the wheel be then turned round by hand, the pin will describe a circle both round the nail, and in the space it moves through. But if the props be taken away, the horses put to, and the chariot driven over a piece of ground which is circularly convex, the nail in the axle will describe a circular curve, and the pin in the nave will still describe a circle round the progressive nail in the axle, but not in the space through which it moves. In this case, the curve described by the nail will resemble in miniature as much of the Earth's annual path round the Sun, as it describes whilst the Moon goes as often round the Earth as the pin does round the nail: and the curve described by the nail will have some resemblance of the Moon's path during so many lunations.

An idea of the Earth's path and the Moon's.

Let us now suppose that the radius of the circular curve described by the nail in the axle, is to the radius of the circle, which the pin in the nave describes round the axle, as 337½ to 1; which is the proportion of the radius or semidiameter of the Earth's orbit to that of the Moon's; or of the circular curve *A* 1 2 3 4 5 6 7 *B*, &c. to the little circle *a*, and then, whilst the progressive nail describes the said curve from *A* to *E*, the pin will go once round the nail with regard to the centre of its path, and in so doing will describe the curve *a b c d e*. The former will be a true representation of the

Plate VII. Fig. 2.

[*] In this place, we may consider the orbits of all the satellites as circular, with respect to their primary planets; because the excentricities of their orbits are too small to affect the phenomena here described.

Earth's path for one lunation, and the latter of the Moon's for that time. Here we may set aside the inequalities of the Moon's motion, and also the Earth's moving round its common centre of gravity and the Moon's: all which, if they were truly copied in this experiment, would not sensibly alter the figure of the paths described by the nail and pin, even though they should rub against a plain upright surface all the way, and leave their tracks visible upon it. And if the chariot was driven forward on such a convex piece of ground, so as to turn the wheel several times round, the track of the pin in the nave would still be concave toward the centre of the circular curve described by the pin in the axle; as the Moon's path is always concave to the Sun in the centre of the Earth's annual orbit.

In this diagram, the thickest curve line *ABCDE*, with the numeral figures set to it, represents as much of the Earth's annual orbit as it describes in 32 days from west to east, the little circles at *a*, *b*, *c*, *d*, *e*, shew the Moon's orbit in due proportion to the Earth's; and the smallest curve *a b c d e f* represents the line of the Moon's path in the heavens for 32 days, accounted from any particular new Moon at *a*. The machine, Plate VII. Fig. 5. Fig. 5, is for delineating the Moon's path, and will be described, with the rest of my astronomical machinery, in the last chapter. The Sun is supposed to be in the centre of the curve *A* 1 2 3 4 5 6 7 *B*, &c. and the small dotted circles upon it represent the Moon's orbit, of which the radius is in the same proportion to the Earth's path in this scheme, that the radius of the Moon's orbit in the heavens bears to the radius of the Earth's annual path round the Sun: that is, as 240,000 to 81,000,000, or as 1 to 337½.

Proportion of the Moon's orbit to the Earth's.

When the Earth is at *A*, the new Moon is at *a*; and in the 7 days that the Earth describes the curve 1 2 3 4 5 6 7, the Moon in accompanying the Earth describes the curve *a b*; and is in her first quarter at *b* when the Earth is at *B*. As the Earth describes the curve *B* 8 9 10 11 12 13 14, the Moon describes the curve *b c*; and is at *c*, opposite to the Sun, when the Earth is at *C*. Whilst the Earth describes the curve *C* 15 16 17 18 19 20 21 22, the Moon describes the curve *c d*; and is in her third quarter at *d* when the Earth is at *D*. And lastly, whilst the Earth describes the curve *D* 23 24 25 26

Fig. 2.

27 28 29, the Moon describes the curve *d e*; and is again in conjunction at *e* with the Sun when the Earth is at *E*, between the 29th and 30th day of the Moon's age, accounted by the numeral figures from the new Moon at *A*. In describing the curve *a b c d e*, the Moon goes round the progressive Earth as really as if she had kept in the dotted circle *A*, and the Earth continued immoveable in the centre of that circle.

And thus we see, that although the Moon goes round the Earth in a circle, with respect to the Earth's centre, her real path in the heavens is not very different in appearance from the Earth's path. To shew that the Moon's path is concave to the Sun, even at the time of change, it is carried on a little farther into a second lunation, as to *f*.

The Moon's motion always concave towards the Sun.

267 The Moon's absolute motion from her change to her first quarter, or from *a* to *b*, is so much slower than the Earth's, that she falls 240,000 miles (equal to the semidiameter of her orbit) behind the Earth at her first quarter in *b*, when the Earth is in *B*, that is, she falls back a space equal to her distance from the Earth. From that time her motion is gradually accelerated to her opposition or full at *c*, and then she is come up as far as the Earth, having regained what she lost in her first quarter from *a* to *b*. From the full to the last quarter at *d* her motion continues accelerated, so as to be just as far before the Earth at *d*, as she was behind it at her first quarter in *b*. But, from *d* to *e* her motion is so retarded, that she loses as much with respect to the Earth as is equal to her distance from it, or to the semidiameter of her orbit; and by that means she comes to *e*, and is then in conjunction with the Sun as seen from the Earth at *E*. Hence we find, that the Moon's absolute motion is slower than the Earth's from her third quarter to her first; and swifter than the Earth's from her first quarter to her third: her path being less curved than the Earth's in the former case, and more in the latter. Yet it is still bent the same way towards the Sun; for if we imagine the concavity of the Earth's orbit to be measured by the length of a perpendicular line *C g*, let down from the Earth's place upon the straight line *b g d* at the full of the Moon, and connecting the places of the Earth at the end of the Moon's first and third quarters, that length will be about

How her motion is alternately retarded and accelerated.

640,000 miles; and the Moon, when new, only approaching nearer to the Sun by 240,000 miles than the Earth is, the length of the perpendicular let down from her place at that time upon the same straight line, and which shews the concavity of that part of her path, will be about 400,000 miles.

A difficulty removed. 268. The Moon's path being concave to the Sun throughout, demonstrates that her gravity towards the Sun, at her conjunction, exceeds her gravity towards the Earth. And if we consider that the quantity of matter in the Sun is almost 230,000 times as great as the quantity of matter in the Earth, and that the attraction of each body diminishes as the square of the distance from it increases, we shall soon find, that the point of equal attraction between the Earth and the Sun is about 70,000 miles nearer the Earth than the Moon is at her change. It may then appear surprising that the Moon does not abandon the Earth when she is between it and the Sun, because she is considerably more attracted by the Sun than by the Earth at that time. But this difficulty vanishes when we consider that a common impulse on any system of bodies affects not their relative motions; but that they will continue to attract, impel, or circulate round one another, in the same manner as if there was no such impulse The Moon is so near the Earth, and both of them so far from the Sun, that the attractive power of the Sun may be considered as equal on both: and therefore the Moon will continue to circulate round the Earth in the same manner as if the Sun did not attract them at all; like bodies in the cabin of a ship, which may move round or impel one another in the same manner when the ship is under sail, as when it is at rest; because they are all equally affected by the common motion of the ship. If by any other cause, such as the near approach of a comet, the Moon's distance from theEarth should happen to be so much increased, that the difference of their gravitating forces towards the Sun should exceed that of the Moon towards the Earth; in that case the Moon, when in conjunction, would abandon the Earth, and be either drawn into the Sun, or comet, or circulate round about it.

Plate VII. Fig. 2. 269. The curves which Jupiter's satellites describe are all of different sorts from the path described by our Moon, although these satellites go round Jupiter, as the

Moon goes round the Earth. Let *A B C D E*, &c. be as much of Jupiter's orbit as he describes in 18 days from *A* to *T*; and the curves *a*, *b*, *c*, *d*, will be the paths of his four moons going round him in his progressive motion.

Let us suppose all these moons to set out from a conjunction with the Sun, as seen from Jupiter at *A*; then his first or nearest moon will be at *a*, his second at *b*, his third at *c*, and his fourth at *d*. At the end of 24 terrestrial hours after this conjunction, Jupiter has moved to *B*, his first moon or satellite has described the curve *a* 1, his second the curve *b* 1, his third *c* 1, and his fourth *d* 1. The next day, when Jupiter is at *C*, his first satellite has described the curve *a* 2, from its conjunction, his second the curve *b* 2, his third the curve *c* 2, and his fourth the curve *d* 2, and so on. The numeral figures under the capital letters shew Jupiter's place in his path every day for 18 days, accounted from *A* to *T*; and the like figures set to the paths of his satellites, shew where they are at the like times. The first satellite, almost under *C*, is stationary at + as seen from the Sun, and retrograde from + to 2: at 2 it appears stationary again, and thence it moves forward until it has passed 3, and is twice stationary, and once retrograde between 3 and 4. The path of this satellite intersects itself every 42½ hours, making such loops as in the diagram at 2. 3. 5. 7. 9. 10. 12. 14. 16. 18. a little after every conjunction. The second satellite *b*, moving slower, barely crosses its path every 3 days 13 hours; as at 4. 7. 11. 14. 18. making only 5 loops and as many conjunctions in the time that the first makes ten. The third satellite *c* moving still slower, and having described the curve *c* 1. 2. 3. 4. 5. 6. 7. comes to an angle at 7 in conjunction with the Sun at the end of 7 days 4 hours; and so goes on to describe such another curve 7. 8. 9. 10. 11. 12. 13. 14. and is at 14 in its next conjunction. The fourth satellite *d* is always progressive, making neither loops nor angles in the heavens; but comes to its next conjunction at *e*, between the numeral [fig]ures 16 and 17, or in 16 days 18 hours. In order to have [a] tolerable good figure of the paths of these satellites, I took the following method.

The absolute path of Jupiter and his satellites delineated.

Fig. 3.

Having drawn their orbits on a card, in proportion to their relative distances from Jupiter, I mea-

Fig. 4.

sured the radius of the orbit of the fourth satellite, which was an inch and $\frac{14}{100}$ parts of an inch; I then multiplied this by 424 for the radius of Jupiter's orbit, because Jupiter is 424 times as far from the Sun's centre as his fourth satellite is from his centre, and the product thence arising was $483\frac{36}{100}$ inches. Then taking a small cord of this length, and fixing one end of it to the floor of a long room by a nail, with a black-lead pencil at the other end, I drew the curve *ABCD*, &c. and set off a degree and half thereon, from *A* to *T*; because Jupiter moves only so much, whilst his outermost satellite goes once round him, and somewhat more; so that this small portion of so large a circle differs but very little from a straight line. This done, I divided the space *AT* into 18 equal parts, as *AB*, *BC*, &c. for the daily progress of Jupiter, and each part into 24 for his hourly progress. The orbit of each satellite was also divided into as many equal parts as the satellite is hours in finishing its synodical period round Jupiter. Then drawing a right line through the centre of the card, as a diameter to all the four orbits upon it, I put the card upon the line of Jupiter's motion, and transferred it to every horary division thereon, keeping always the same diameter line on the line of Jupiter's path; and running a pin through each horary division in the orbit of each satellite, as the card was gradually transferred along the line *ABCD*, &c. of Jupiter's motion, I marked points for every hour through the card for the curves described by the satellites, as the primary planet in the centre of the card was carried forward on the line; and so finished the figure, by drawing the lines of each satellite's motion through those (almost innumerable) points: by which means this is, perhaps, as true a figure of the paths of these satellites as can be desired.

How to delineate the paths of Jupiter's Moons.

Fig. 3.

And in the same manner might those of Saturn's satellites be delineated.

And Saturn's.

270. It appears by the scheme, that the three first satellites come almost into the same line of position every seventh day; the first being only a little behind with the second, and the second behind with the third. But the period of the fourth satellite is so incommensurate to the periods of the other three, that it cannot be guessed at by the diagram when it would fall again into a line of conjunction

The grand period of Jupiter's moons.

with them between Jupiter and the Sun. And no wonder; for supposing them all to have been once in conjunction, it will require 3,087,043,493,260 years to bring them in conjunction again. See § 73.

271. In Fig. 4, we have the proportions of the orbits of Saturn's five satellites, and of Jupiter's four to one another, to our Moon's orbit, and to the disc of the Sun. *S* is the Sun; *Mm* the Moon's orbit (the Earth supposed to be at *E*); *J* Jupiter; 1. 2. 3. 4. the orbits of his four moons or satellites; *Sat.* Saturn; and 1. 2. 3. 4. 5. the orbits of his five moons. Hence it appears, that the Sun would much more than fill the whole orbit of the Moon; for the Sun's diameter is 763,000 miles, and the diameter of the Moon's orbit only 480,000. In proportion to all these orbits of the satellites, the radius of Saturn's annual orbit would be $21\frac{1}{4}$ yards, of Jupiter's orbit $11\frac{2}{3}$, and of the Earth's $2\frac{1}{4}$, taking them in round numbers.

The proportions of the orbits of the planets and satellites.
Fig. 4.

272. The annexed table shews at once what proportion the orbits, revolutions, and velocities, of all the satellites bear to those of their primary planets, and what sort of curves the several satellites describe. For those satellites, whose velocities round their primaries are greater than the velocities of their primaries in open space, make loops at their conjunctions, § 269; appearing retrograde as seen from the Sun whilst they describe the inferior parts of their orbits, and direct whilst they describe the superior. This is the case with Jupiter's first and second satellites, and with Saturn's first. But those satellites, whose velocities are less than the velocities of their primary planets, move direct in their whole circumvolutions; which is the case of the third and fourth satellites of Jupiter, and of the second, third, fourth, and fifth satellites of Saturn, as well as of our satellite the Moon: but the Moon is the only satellite whose motion is always concave to the Sun.

The Satellites	Proportion of the radius of the planet's orbit to the radius of the orbit of each satellite.	Proportion of the time of the planet's revolution to the revolution of each satellite.	Proportion of the velocity of each satellite to the velocity of its primary planet.
of Saturn. 1	As 5322 to 1	As 5738 to 1	As 5738 to 5322
2	4155 1	3912 1	3912 4155
3	2954 1	2347 1	2347 2954
4	1295 1	674 1	674 1295
5	432 1	134 1	134 432
of Jupiter. 1	As 1851 to 1	As 2445 to 1	As 2445 to 1851
2	1165 1	1219 1	1219 1165
3	731 1	604 1	604 731
4	424 1	258 1	258 424
The Moon.	As $337\frac{1}{2}$ to 1	As $12\frac{1}{3}$ to 1	As $12\frac{1}{3}$ to $337\frac{1}{2}$

There is a table of this sort in De la Caille's Astronomy, but it is very different from the above, which I have computed from our English accounts of the periods and distances of these planets and satellites.

CHAP. XVI.

THE PHENOMENA OF THE HARVEST MOON EXPLAINED BY A COMMON GLOBE—THE YEARS IN WHICH THE HARVEST-MOONS ARE LEAST AND MOST BENEFICIAL, FROM 1751 TO 1861—THE LONG DURATION OF MOON-LIGHT AT THE POLES IN WINTER.

No harvest Moon at the equator.

273. It is generally believed that the Moon rises about 50 minuets later every day than on the preceding; but this is true only with regard to places on the equator. In places of considerable latitude there is a remarkable difference, especially in the harvest time, with which farmers were better acquainted than astronomers till of late; and gratefully ascribed the early rising of the full Moon at that time of the year to the goodness of God, not doubting that he had ordered it so on purpose to give them an immediate supply of moon-light after sun-set, for their greater conveniency in reaping the fruits of the Earth.

* In this instance of the harvest moon, as in many others discoverable by astronomy, the wisdom and beneficence of the Deity is conspicuous, who really ordered the course of the Moon so as to bestow more or less light on all parts of the Earth, as their several circumstances and seasons render it more or less serviceable. About the equator, where there is no variety of seasons, and the weather changes seldom, and at stated times, moon-light is not necessary for gathering in the produce of the ground; and there the Moon rises about 50 minutes later every day or night than on the former. In considerable distances from the equator, where the weather and seasons are more uncertain, the autumnal full Moons rise very soon after sun-set for several evenings together. At the polar circles, where the mild season is of very short duration, the autumnal full Moon rises at sun-set from the first to the third quarter. And at the poles, where the Sun is for half a year absent, the winter full Moons shine constantly without setting from the first to the third quarter.

But remarkable according to the distance of places from it.

It is soon said that all these phenomena are owing to the different angles made by the horizon and different parts of the Moon's orbit; and that the Moon can be full but once or twice in a year, in those parts of her orbit which rise with the least angles. But to explain this subject intelligibly, we must dwell much longer upon it.

The reason of this.

274. The[1] plane of the equinoctial is perpendicular to the Earth's axis: and therefore, as the Earth turns round its axis, all parts of the equinoctial make equal angles with the horizon both at rising and setting; so that equal portions of it always rise or set in equal times. Consequently, if the Moon's motion were equable, and in the equinoctial at the rate of 12 degrees 11 minutes from the Sun every day, as it is in her orbit, she would rise and set 50 minutes later every day than on the preceding; for 12 degrees 11 minutes of the equinoctial rise or set in 50 minutes of time in all latitudes.

275. But the Moon's motion is so nearly in the ecliptic, that we may consider her at present as moving in it. Now the different parts of the ecliptic, on account of its obliquity to the

[1] If a globe be cut quite through upon any circle, the flat surface where it is so divided is the *plane* of that circle.

Earth's axis, make very different angles with the horizon as they rise or set. Those parts or signs which rise with the smallest angles set with the greatest, and *vice versa*. In equal times, whenever this angle is least, a greater portion of the ecliptic rises than when the angle is larger; as may be seen by elevating the pole of a globe to any considerable latitude, and then turning it round its axis in the horizon. Consequently, when the Moon is in those signs which rise or set with the smallest angles, she rises or sets with the least difference of time; and with the greatest difference in those signs which rise or set with the greatest angles.

Plate III. Fig. 3. But, because all who read this treatise may not be provided with globes, though in this case it is requisite to know how to use them, we shall substitute the figure of a globe; in which *F U P* is the axis, ♋ *T R* the tropic of Cancer, *L t* ♑ the tropic of Capricorn, ♋ *E U* ♑ the ecliptic touching both the tropics, which are 47 degrees from each other, and *A B* the horizon. The equator, being in the middle between the tropics, is cut by the ecliptic in two opposite points, which are the beginnings of ♈ Aries and ♎ Libra. *K* is the hour-circle with its index, *F* the north pole of the globe elevated to a considerable latitude, suppose 40 degrees above the horizon; and *P* the south pole depressed as much below it. Because of the oblique position of the sphere in this latitude, the ecliptic has the high elevation *N* ♋ above the horizon, making the angle *N U* ♋ of 73½ degrees with it, when ♋ Cancer is on the meridian, at which time ♎ Libra rises in the east. But let the globe be turned half round its axis, till ♑ Capricorn comes to the meridian, and ♈ Aries rises in the east, and then the ecliptic will have the low elevation *N L* above the horizon, making only an angle *N U L* of 26½ degrees with it; which is 47 degrees less than the former angle, equal to the distance between the tropics.

The different angles made by the ecliptic and horizon.

Least and greatest when. 276. In northern latitudes, the smallest angle made by the ecliptic and horizon is when Aries rises, at which time Libra sets: the greatest when Libra rises, at which time Aries sets. From the rising of Aries to the rising of Libra (which is twelve* sydereal hours), the angle

* The ecliptic, together with the fixed stars, make 366¼ apparent diurnal revolu-

increases; and from the rising of Libra to the rising of Aries it decreases in the same proportion. By this article and the preceding, it appears that the ecliptic rises fastest about Aries, and slowest about Libra.

277. On the parallel of London, as much of the ecliptic rises about Pisces and Aries in two hours as the Moon goes through in six days: and, therefore, whilst the Moon is in these signs, she differs but two hours in rising for six days together; that is about 20 minutes later every day or night than on the preceding, at a mean rate. But in fourteen days afterwards, the Moon comes to Virgo and Libra, which are the opposite signs to Pisces and Aries; and then she differs almost four times as much in rising, namely, 1 hour and about 15 minutes later every day or night than the former, whilst she is in these signs. The annexed Table shews the daily mean difference of the Moon's rising and setting on the parallel of London, for 28 days, in which time the Moon finishes her period round the ecliptic, and gets 9° into the same sign from the beginning of which she set out. So it appears by the Table, that when the Moon is in ♍ and ♎ she rises an hour and a quarter later every day than she rose on the former; and differs only 28, 24, 20, 18 or 17, minutes in setting. But when she comes to ♓ and ♈, she is only 20 or 17 minutes later in setting.

Result of the quantity of this angle at London.

Days.	Signs.	Degrees.	Rising Diff. H.	Rising Diff. M.	Setting Diff. H.	Setting Diff. M.
1	♋	13	1	5	0	50
2		26	1	10	0	43
3	♌	10	1	14	0	37
4		23	1	17	0	32
5	♍	6	1	16	0	28
6		19	1	15	0	24
7	♎	2	1	15	0	20
8		15	1	15	0	18
9		28	1	15	0	17
10	♏	12	1	15	0	22
11		25	1	14	0	30
12	♐	8	1	13	0	39
13		21	1	10	0	47
14	♑	4	1	4	0	56
15		17	0	46	1	5
16	♒	1	0	40	1	8
17		14	0	35	1	12
18		27	0	30	1	15
19	♓	10	0	25	1	16
20		23	0	20	1	17
21	♈	7	0	17	1	16
22		20	0	17	1	15
23	♉	3	0	20	1	15
24		16	0	24	1	15
25		29	0	30	1	14
26	♊	13	0	40	1	13
27		26	0	56	1	7
28	♋	9	1	00	1	58

278. All these things will be made plain by putting small

tions about the Earth in a year; the Sun only 365¼. Therefore the stars gain 3 minutes 56 seconds upon the Sun every day; so that a sydereal day contains only 23 hours 56 minutes of mean solar time; and a natural or solar day 24 hours. Hence 12 sydereal hours are 1 minute 58 seconds shorter than 12 solar.

patches on the ecliptic of a globe, as far from one another as the Moon moves from any point of the celestial ecliptic in 24 hours, which, at a mean rate, is[3] $13\frac{1}{6}$ degrees; and then, in turning the globe round, observe the rising and setting of the patches in the horizon, as the index points out the different times in the hour circle. A few of these patches are represented by dots at 0 1 2 3, &c. on the ecliptic, which has the position *L U I* when Aries rises in the east; and by the dots 0 1 2 3, &c. when Libra rises in the east, at which time the ecliptic has the position ♎ *U* ♑: making an angle of 62 degrees with the horizon in the latter case, and an angle of no more than 15 degrees with it in the former; supposing the globe rectified to the latitude of London

Plate III. Fig. 2.

279. Having rectified the globe, turn it until the patch at 0, about the beginning of ♓ Pisces in the half *L U I* of the ecliptic, comes to the eastern side of the horizon: and then, keeping the ball steady, set the hour-index to XII, because *that* hour may perhaps be more easily remembered than any other Then turn the globe round westward, and in that time, suppose the patch 0 to have moved thence to 1, $13\frac{1}{6}$ degrees, whilst the Earth turns once round its axis, and you will see that 1 rises only about 20 minutes later than 0 did on the day before. Turn the globe round again, and in that time suppose the same patch to have moved from 1 to 2; and it will rise only 20 minutes later by the hour-index, than it did at 1 on the day or turn before At the end of the next turn, suppose the patch to have gone from 2 to 3 at *U*, and it will rise 20 minutes later than it did at 2. And so on for six turns, in which time there will scarce be two hours difference; nor would there have been so much, if the 6 degrees of the Sun's motion in that time had been allowed for. At the first turn the patch rises south of the east, at the middle turn due east, and at the last turn north of the east. But these patches will be 9 hours of setting on the western side of the horizon, which shews, that the Moon will be so much later of setting in that week in which she moves through these two signs. The cause of this difference is evi-

[3] The Sun advances almost a degree in the ecliptic in 24 hours, the same way that the Moon moves; and, therefore, the Moon, by advancing $13\frac{1}{6}$ degrees in that time, goes little more than 12 degrees farther from the Sun than she was on the day before.

dent; for Pisces and Aries make only an angle of 15 degrees with the horizon when they rise; but they make an angle of 62 degrees with it when they set. As the signs Taurus, Gemini, Cancer, Leo, Virgo, and Libra, rise successively, the angle increases gradually which they make with the horizon, and decreases in the same proportion as they set. And for that reason, the Moon differs gradually more in the time of her rising every day whilst she is in these signs, and less in her setting: after which, through the other six signs, viz. Scorpio, Sagittarius, Capricorn, Aquarius, Pisces, and Aries, the rising difference becomes less every day, until it be at the least of all, namely, in Pisces and Aries

280 The Moon goes round the ecliptic in 27 days 8 hours; but not from change to change in less than 29 days 12 hours: so that she is in Pisces and Aries at least once in every lunation, and in some lunations twice.

Why the Moon is always full in different signs

281 If the Earth had no annual motion, the Sun would never appear to shift his place in the ecliptic. And then every new Moon would fall in the same sign and degree of the ecliptic, and every full Moon in the opposite: for the Moon would go precisely round the ecliptic from change to change. So that if the Moon was once full in Pisces or Aries, she would always be full when she came round to the same sign and degree again. And as the full Moon rises at sun-set (because when any point of the ecliptic sets, the opposite point rises), she would constantly rise within two hours of sun-set, on the parallel of London, during the week in which she was full. But in the time that the Moon goes round the ecliptic from any conjunction or opposition, the Earth goes almost a sign forward: and, therefore, the Sun will seem to go as far forward in that time, namely, $27\frac{1}{2}$ degrees; so that the Moon must go $27\frac{1}{2}$ degrees more than round, and as much farther as the Sun advances in that interval, which is $2\frac{1}{12}$ degrees, before she can be in conjunction with, or opposite to the Sun again. Hence it is evident, that there can be but one conjunction or opposition of the Sun and Moon in a year, in any particular part of the ecliptic. This may be familiarly exemplified by the hour and minute hands of a watch, which are never in conjunction or opposition in that part of the dial-plate where they were so last before.

Her periodical and synodical revolution exemplified.

And, indeed, if we compare the 12 hours on the dial-plate to

the 12 signs of the ecliptic, the hour-hand to the Sun, and the minute-hand to the Moon, we shall have a tolerably near resemblance in miniature to the motions of our great celestial luminaries. The only difference is, that whilst the Sun goes once round the ecliptic, the Moon makes $12\frac{1}{3}$ conjunctions with him: but whilst the hour-hand goes round the dial-plate, the minute-hand makes only 11 conjunctions with it; because the minute-hand moves slower in respect to the hour-hand than the Moon does with regard to the Sun.

The harvest and hunter's Moon.

282. As the Moon can never be full but when she is opposite to the Sun, and the Sun is never in Virgo and Libra but in our autumnal months, it is plain that the Moon is never full in the opposite signs, Pisces and Aries, but in these two months. And, therefore, we can have only two full Moons in the year, which rise so near the time of sun-set for a week together, as above mentioned. The former of these is called the *harvest Moon*, and the latter the *hunter's Moon*.

Why the Moon's regular rising is never perceived but in harvest.

283. Here it will probably be asked, why we never observe this remarkable rising of the Moon but in harvest, seeing she is in Pisces and Aries 12 times in the year besides; and must then rise with as little difference of time as in harvest? The answer is plain; for in winter these signs rise at noon; and being then only a quarter of a circle distant from the Sun, the Moon in them is in her first quarter: but when the Sun is above the horizon, the Moon's rising is neither regarded nor perceived. In spring these signs rise with the Sun, because he is then in them; and as the Moon changes in them at that time of the year, she is quite invisible. In summer they rise about midnight, and the Sun being then three signs, or a quarter of a circle before them, the Moon is in them about her third quarter; when rising so late, and giving but very little light, her rising passes unobserved. And, in autumn, these signs being opposite to the Sun, rise when he sets, with the Moon in opposition, or at the full, which makes her rising very conspicuous.

284. At the equator, the north and south poles lie in the horizon; and, therefore, the ecliptic makes the same angle southward with the horizon when Aries rises, as it does northward when Libra rises. Consequently, as the Moon at all the fore-mentioned patches rises and sets nearly at equal angles with

the horizon all the year round, and about 50 minutes later every day or night than on the preceding, there can be no particular harvest Moon at the equator.

285. The farther that any place is from the equator, if it be not beyond the polar circle, the angle gradually diminishes, which the ecliptic and horizon make when Pisces and Aries rise: and, therefore, when the Moon is in these signs she rises with a nearly proportionable difference later every day than on the former, and is for that reason the more remarkable about the full, until we come to the polar circles, or 66 degrees from the equator; in which latitude the ecliptic and horizon become coincident every day for a moment, at the same sydereal hour (or 3 minutes 56 seconds sooner every day than the former), and the very next moment one-half of the ecliptic, containing Capricorn, Aquarius, Pisces, Aries, Taurus, and Gemini, rises, and the opposite half sets. Therefore, whilst the Moon is going from the beginning of Capricorn to the beginning of Cancer, which is almost 14 days, she rises at the same sydereal hour; and in autumn just at sun-set, because all the half of the ecliptic, in which the Sun is at that time, sets at the same sydereal hour, and the opposite half rises; that is, 3 minutes 56 seconds, of mean solar time, sooner every day than on the day before. So, whilst the Moon is going from Capricorn to Cancer, she rises earlier every day than on the preceding; contrary to what she does at all places between the polar circles. But during the above 14 days, the Moon is 24 sydereal hours later in setting: for the six signs, which rise all at once on the eastern side of the horizon, are 24 hours in setting on the western side of it; as any one may see by making chalk marks at the beginning of Capricorn and of Cancer, and then, having elevated the pole 66½ degrees, turn the globe slowly round its axis, and observe the rising and setting of the ecliptic. As the beginning of Aries is equally distant from the beginning of Cancer and of Capricorn, it is in the middle of that half of the ecliptic which rises all at once. And when the Sun is at the beginning of Libra, he is in the middle of the other half. Therefore, when the Sun is in Libra, and the Moon in Capricorn, the Moon is a quarter of a circle before the Sun; opposite to him, and consequently full in Aries, and a quarter of a circle behind him, when in Cancer. But when Libra rises, Aries sets, and all that half of the ecliptic of which Aries is the middle;

and, therefore, at that time of the year, the Moon rises at sunset from her first to her third quarter.

The harvest moons regular on both sides of the equator.

286. In northern latitudes, the autumnal full moons are in Pisces and Aries, and the vernal full moons in Virgo and Libra. In southern latitudes just the reverse, because the seasons are contrary. But Virgo and Libra rise at as small angles with the horizon in southern latitudes, as Pisces and Aries do in the northern, and, therefore, the harvest moons are just as regular on one side of the equator as on the other.

287. As these signs which rise with the least angles, set with the greatest, the vernal full moons differ as much in their times of rising every night, as the autumnal full moons differ in their times of setting, and set with as little difference as the autumnal full moons rise: the one being in all cases the reverse of the other.

288. Hitherto, for the sake of plainness, we have supposed the Moon to move in the ecliptic, from which the Sun never deviates. But the orbit in which the Moon really moves is different from the ecliptic, one-half being elevated $5\frac{1}{3}$ degrees above it, and the other half as much depressed below it. The Moon's orbit, therefore, intersects the ecliptic in two points diametrically opposite to each other, and these intersections are called the *Moon's nodes*. So the Moon can never be in the ecliptic but when she is in either of her nodes, which is at least twice in every course from change to change, and sometimes thrice. For, as the Moon goes almost a whole sign more than round her orbit from change to change, if she passes by either node about the time of change, she will pass by the other in about 14 days after, and come round to the former node 2 days again before the next change. That node from which the Moon begins to ascend northward, or above the ecliptic, in northern latitudes, is called the *Ascending node*, and the other the *Descending node*, because the Moon, when she passes by it, descends below the ecliptic southward.

The Moon's nodes

289. The Moon's oblique motion with regard to the ecliptic, causes some difference in the times of her rising and setting, from what is already mentioned. For when she is northward of the ecliptic, she rises sooner and sets later than if she moved in the ecliptic: and when she is southward of the ecliptic, she rises later and sets sooner. This difference is variable, even in

the same signs, because the nodes shift backward about $19\frac{2}{3}$ degrees in the ecliptic every year; and so go round it contrary to the order of signs in 18 years 225 days.

290. When the ascending node is in Aries, the southern half of the Moon's orbit makes an angle of $5\frac{1}{3}$ degrees less with the horizon than the ecliptic does, when Aries rises in northern latitudes: for which reason, the Moon rises with less difference of time whilst she is in Pisces and Aries, than she would do if she kept in the ecliptic. But in 9 years and 112 days afterwards, the descending node comes to Aries; and then the Moon's orbit makes an angle $5\frac{1}{3}$ degrees greater with the horizon when Aries rises, than the ecliptic does at that time, which causes the Moon to rise with greater difference of time in Pisces and Aries, than if she moved in the ecliptic.

291. To be a little more particular; when the ascending node is in Aries, the angle is only $9\frac{2}{3}$ degrees on the parallel of London when Aries rises. But when the descending node comes to Aries, the angle is $20\frac{1}{3}$ degrees: this occasions as great a difference of the Moon's rising in the same signs every 9 years, as there would be on two parallels $10\frac{2}{3}$ degrees from one another, if the Moon's course were in the ecliptic. The following table shews how much the obliquity of the Moon's orbit affects her rising and setting on the parallel of London, from the 12th to the 18th day of her age, supposing her to be full at the autumnal equinox: and then, either in the ascending node, highest part of her orbit, descending node, or lowest part of her orbit. *M* signifies morning, *A* afternoon; and the line at the foot of the table shews a week's difference in rising and setting.

Moon's Age.	Full in her ascending node.				In the highest part of her orbit.				Full in her descending node.				In the lowest part of her orbit.			
	Rises at		Sets at		Rises at		Sets at		Rises at		Sets at		Rises at		Sets at	
	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.
12	5 *A*	15	3 *M*	20	4 *A*	30	3 *M*	15	4 *A*	32	3 *M*	40	5 *A*	16	3 *M*	0
13	5	32	4	25	4	50	4	45	5	15	4	20	6	0	4	15
14	5	48	5	30	5	15	6	0	5	45	5	40	6	20	5	28
15	6	5	7	0	5	42	7	20	6	15	6	56	6	45	6	32
16	6	20	8	15	6	2	8	35	6	46	8	0	7	8	7	45
17	6	36	9	12	6	26	9	45	7	18	9	15	7	30	9	15
18	6	54	10	30	7	0	10	40	8	0	10	20	7	52	10	0
Dif.	13	9	7	10	2	30	7	25	3	26	6	40	2	36	7	0

This table was not computed, but only estimated as near as could be done from a common globe, on which the Moon's orbit was delineated with a black-lead pencil. It may at first sight appear erroneous, since, as we have supposed the Moon to be full in either node at the autumnal equinox, she ought by the table to rise just at 6 o'clock, or at sun set, on the 15th day of her age; being in the ecliptic at that time. But it must be considered, that the Moon is only $14\frac{3}{4}$ days old when she is full, and, therefore, in both cases she is a little past the node on the 15th day, being above it at one time, and below it at the other.

The period of the harvest Moon.

292. As there is a complete revolution of the nodes in $18\frac{2}{3}$ years, there must be a regular period of all the varieties which can happen in the rising and setting of the Moon during that time. But this shifting of the nodes never affects the Moon's rising so much, even in her quickest descending latitude, as not to allow us still the benefit of her rising nearer the time of sun set, for a few days together about the full in harvest, than when she is full at any other time of the year. The following table shews in what years the harvest-moons are least beneficial as to the times of their rising, and in what years most, from 1751 to 1861. The column of years under the letter *L*, are those in which the harvest moons are least of all beneficial, because they fall about the descending node: and those under *M* are the most of all beneficial, because they fall about the ascending node. In all the columns from *N* to *S*, the harvest-moons descend gradually in the lunar orbit, and rise to less heights above the horizon. From *S* to *N* they ascend in the same proportion, and rise to greater heights above the horizon. In both the columns under *S*, the harvest-moons are in the lowest part of the Moon's orbit, that is, farthest south of the ecliptic; and, therefore, stay shortest of all above the horizon: in the columns under *N* just the reverse. And in both cases, their rising, though not at the same times, are nearly the same with regard to difference of time, as if the Moon's orbit were coincident with the ecliptic.

Years in which the Harvest Moons are least beneficial.

N				L				S	
1751	1752	1753	1754	1755	1756	1757	1758	1759	
1770	1771	1772	1773	1774	1775	1776	1777	1778	
1788	1789	1790	1791	1792	1793	1794	1795	1796	1797
1807	1808	1809	1810	1811	1812	1813	1814	1815	
1826	1827	1828	1829	1830	1831	1832	1833	1834	
1844	1845	1846	1847	1848	1849	1850	1851	1852	

Years in which they are most beneficial.

S				M				N	
1760	1761	1762	1763	1764	1765	1766	1767	1768	1769
1779	1780	1781	1782	1783	1784	1785	1786	1787	
1798	1799	1800	1801	1802	1803	1804	1805	1806	
1816	1817	1818	1819	1820	1821	1822	1823	1824	1825
1835	1836	1837	1838	1839	1840	1841	1842	1843	
1853	1854	1855	1856	1857	1858	1859	1860	1861	

293. At the polar circles, when the Sun touches the summer tropic, he continues 24 hours above the horizon; and 24 hours below it when he touches the winter tropic. For the same reason, the full Moon neither rises in summer, nor sets in winter, considering her as moving in the ecliptic. For the winter full moon being as high in the ecliptic as the summer sun, must therefore continue as long above the horizon; and the summer full moon being as low in the ecliptic as the winter sun, can no more rise than he does. But these are only the two full moons which happen about the tropics, for all the others rise and set. In summer the full moons are low, and their stay is short above the horizon, when the nights are short, and we have least occasion for moon-light: in winter they go high, and stay long above the horizon, when the nights are long, and we want the greatest quantity of moon-light.

The long continuance of moonlight at the poles.

294. At the poles one half of the ecliptic never sets, and the other half never rises: and, therefore, as the Sun is always half a year in describing one half of the ecliptic, and as long in going through the other half, it is natural to imagine that the Sun continues half a year together above the horizon of each pole in its turn, and as long below it; rising to one pole when he sets to the other. This would be exactly the case if there were no refraction: but by the atmosphere's refracting the Sun's rays, he be-

comes visible some days sooner, § 183, and continues some days longer in sight than he would otherwise do: so that he appears above the horizon of either pole before he has got below the horizon of the other. And, as he never goes more than 23½ degrees below the horizon of the poles, they have very little dark night, it being twilight there, as well as at all other places, till the Sun be 18 below the horizon; § 177. The full moon being always opposite to the Sun, can never be seen while the Sun is above the horizon, except when the Moon falls in the northern half of her orbit; for, whenever any point of the ecliptic rises, the opposite point sets. Therefore, as the Sun is above the horizon of the north pole from the 20th of March till the 23d of September, it is plain that the Moon, when full, being opposite to the Sun, must be below the horizon during that half of the year. But when the Sun is in the southern half of the ecliptic, he never rises to the north pole, during which half of the year, every full moon happens in some part of the northern half of the ecliptic, which never sets. Consequently, as the polar inhabitants never see the full Moon in summer, they have her always in the winter, before, at, and after the full shining, for 14 of our days and nights. And when the Sun is at his greatest depression below the horizon, being then in Capricorn, the Moon is at her first quarter in Aries, full in Cancer, and at her third quarter in Libra. And as the beginning of Aries is the rising point of the ecliptic, Cancer the highest, and Libra the setting point, the Moon rises at her first quarter in Aries, is most elevated above the horizon, and full in Cancer, and sets at the beginning of Libra in her third quarter, having continued visible for 14 diurnal rotations of the Earth. Thus the poles are supplied one half of the winter-time with constant moon-light in the Sun's absence; and only lose sight of the Moon from her third to her first quarter, while she gives but very little light; and could be but of little, and sometimes of no service to them. A bare view of the figure will make this plain; in which let *S* be the Sun, *e* the Earth in summer, when its north pole *n* inclines toward the Sun, and *E* the Earth in winter, when its north pole declines from him. *SEN* and *NWS* is the horizon of the north pole, which is coincident with the equator; and in both these positions of the Earth, ♈ ♋ ♎ ♑ is the Moon's orbit, in which she goes round the Earth, according to the order of the letters *a b c d*, *A B C D*. When

Plate VIII.
Fig.

the Moon is at *a*, she is in her third quarter to the Earth at *e*, and just rising to the north pole *n*; at *b* she changes, and is at the greatest height above the horizon, as the Sun likewise is; at *c* she is in her first quarter, setting below the horizon; and is lowest of all under it at *d*, when opposite to the Sun, and her enlightened side toward the Earth. But then she is full in view to the south pole *p*; which is as much turned from the Sun as the north pole inclines towards him. Thus, in our summer, the Moon is above the horizon of the north pole, whilst she describes the northern half of the ecliptic ♈ ♋ ♎, or from her third quarter to her first: and below the horizon during her progress through the southern half ♎ ♑ ♈: highest at the change, most depressed at the full. But in winter, when the Earth is at *E*, and its north pole declines from the Sun, the new moon at *D* is at her greatest depression below the horizon *N W S*, and the full moon at *B* at her greatest height above it: rising at her first quarter *A*, and keeping above the horizon till she comes to her third quarter *C*. At a mean state she is 23½ degrees above the horizon at *B* and *b*, and as much below it at *D* and *d*, equal to the inclination of the Earth's axis *F*. *S* ♋ or *S* ♑ are, as it were, a ray of light proceeding from the Sun to the Earth; and shews that when the Earth is at *e*, the Sun is above the horizon, vertical to the tropic of Cancer; and when the Earth is at *E*, he is below the horizon, vertical to the tropic of Capricorn.

CHAP. XVII.

OF THE EBBING AND FLOWING OF THE SEA.

The cause of the tides discovered by Kepler.

295. The cause of the tides was discovered by Kepler, who, in his *Introduction to the Physics of the Heavens*, thus explains it: 'The orb of the attracting power, which is in the Moon, is extended as far as the Earth; and draws the waters under the torrid zone, acting upon places where it is vertical, insensibly on confined seas and bays, but sensibly on the ocean, whose beds are large, and the waters have the liberty of reciprocation, that is, of rising and falling.' And, in the 70th page of his *Lunar Astronomy*—' But the cause of the tides of the sea, appears to be

the bodies of the Sun and Moon drawing the waters of the sea."

Their theory improved by Sir Isaac Newton.

This hint being given, the immortal Sir Isaac Newton improved it, and wrote so amply on the subject, as to make the theory of the tides in a manner quite his own, by discovering the cause of their rising on the side of the Earth opposite to the Moon For Kepler believed, that the presence of the Moon occasioned an impulse which caused another in her absence.

Explained on the Newtonian principles.

Plate IX. Fig. 1.

296. It has been already shewn, § 106, that the power of gravity diminishes as the square of the distance increases; and, therefore, the waters at *Z* on the side of the Earth *ABCDEFGH* next the Moon *M* are more attracted than the central parts of the Earth *O* by the Moon, and the central parts are more attracted by her than the waters on the opposite side of the Earth at *n;* and, therefore, the distance between the Earth's centre and the waters on its surface under and opposite to the Moon will be increased. For, let there be three bodies at *H*, *O*, and *D*; if they are all equally attracted by the body *M*, they will all move equally fast toward it, their mutual distances from each other continuing the same. If the attraction of *M* is unequal, then that body which is most strongly attracted will move fastest, and this will increase its distance from the other body. Therefore, by the law of gravitation, *M* will attract *H* more strongly than it does *O*, by which the distance between *H* and *O* will be increased: and a spectator on *O* will perceive *H* rising higher toward *Z*. In like manner, *O* being more strongly attracted than *D*, it will move farther towards *M* than *D* does: consequently, the distance between *O* and *D* will be increased; and a spectator on *O*, not perceiving his own motion, will see *D* receding farther from him towards *n*, all effects and appearances being the same, whether *D* recedes from *O*, or *O* from *D*.

297. Suppose now there is a number of bodies, as *A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, placed round *O*, so as to form a flexible or fluid ring: then, as the whole is attracted towards *M*, the parts at *H* and *D* will have their distance from *O* increased; whilst the parts at *B* and *F*, being nearly at the same distance from *M* as *O* is, these parts will not recede from one another; but rather, by the oblique attraction of *M*, they will approach nearer to *O*. Hence, the fluid ring will form itself into an ellipse

Z I B L n K F N Z, whose longer axis *n O Z* produced will pass through *M*, and its shorter axis *B O F* will terminate in *B* and *F*. Let the ring be filled with fluid particles, so as to form a sphere round *O*; then, as the whole moves toward *M*, the fluid sphere being lengthened at *Z* and *n*, will assume an oblong or oval form. If *M* is the Moon, *O* the Earth's centre, *A B C D E F G H* the sea covering the Earth's surface, it is evident, by the above reasoning, that whilst the Earth, by its gravity, falls toward the Moon, the water directly below her at *B* will swell and rise gradually towards her: also the water at *D* will recede from the centre (strictly speaking, the centre recedes from *D*), and rise on the opposite side of the Earth: whilst the water at *B* and *F* is depressed, and falls below the former level. Hence, as the Earth turns round its axis from the Moon to the Moon again in 24¾ hours, there will be two tides of flood, and two of ebb in that time, as we find by experience.

298. As this explanation of the ebbing and flowing of the sea is deduced from the Earth's constantly falling toward the Moon by the power of gravity, some may find a difficulty in conceiving how this is possible, when the Moon is full, or in opposition to the Sun; since the Earth revolves about the Sun, and must continually fall towards it, and therefore cannot fall contrary ways at the same time: or, if the Earth is constantly falling towards the Moon, they must come together at last. To remove this difficulty, let it be considered, that it is not the centre of the Earth that describes the annual orbit round the Sun, but the[1] common centre of gravity of the Earth and Moon together: and that whilst the Earth is moving round the Sun, it also describes a circle round that centre of gravity; going as many times round it in one revolution about the Sun as there are lunations or courses of the Moon round the Earth in a year: and, therefore, the Earth is constantly falling towards the Moon, from a tangent to the circle it describes round

[1] This centre is as much nearer the Earth's centre than the Moon's, as the Earth is heavier, or contains a greater quantity of matter than the Moon, namely, about 40 times. If both bodies were suspended on it, they would hang *in equilibrio*. So that dividing 240,000 miles, the Moon's distance from the Earth's centre, by 40, the excess of the Earth's weight above the Moon's, the quotient will be 6000 miles, which is the distance of the common centre of gravity of the Earth and Moon from the Earth's centre.

Plate IX. Fig. 2. the said common centre of gravity. Let M be the Moon, $T W$ part of the Moon's orbit, and C the centre of gravity of the Earth and Moon: whilst the Moon goes round her orbit, the centre of the Earth describes the circle $d\ g\ e$ round C, to which circle $g\ a\ k$ is a tangent: and, therefore, when the Moon has gone from M to a little past W, the Earth has moved from g to e, and in that time has fallen towards the Moon, from the tangent at a to e, and so on, round the whole circle.

299. The Sun's influence in raising the tides is but small in comparison of the Moon's: for, though the Earth's diameter bears a considerable proportion to its distance from the Moon, it is next to nothing when compared to its distance from the Sun. And, therefore, the difference of the Sun's attraction on the sides of the Earth under and opposite to him, is much less than the difference of the Moon's attraction on the sides of the Earth under and opposite to her: and, therefore, the Moon must raise the tides much higher than they can be raised by the Sun.

Why the tides are not highest when the Moon is on the meridian.

300. On this theory, so far as we have explained it, the tides ought to be highest directly under and opposite to the Moon; that is, when the Moon is due north and south. But we find, that in open seas, where the water flows freely, the Moon M is generally past the north and south meridian, as at p, when it is high-water at Z and at n. The reason is obvious; for, though the Moon's attraction was to cease altogether when she was past the meridian, yet the motion of ascent communicated to the water before that time, would make it continue to rise for some time after; much more must it do so when the attraction is only diminished: as a little impulse given to a moving ball will cause it still to move farther than otherwise it could have done; and as experience shews, that the day is hotter about three in the afternoon, than when the Sun is on the meridian, because of the increase made to the heat already imparted.

Fig. 1.

Nor always answer to her being at the same distance from it.

301. The tides answer not always to the same distance of the Moon from the meridian at the same places; but are variously affected by the action of the Sun, which brings them on sooner when the Moon is in her first and third quarters, and keeps them back

later when she is in her second and fourth: because, in the one case, the tide raised by the Sun alone would be earlier than the tide raised by the Moon, and in the other case later.

302. The Moon goes round the Earth in an elliptic orbit, and, therefore, in every lunar month, she approaches nearer to the Earth than her mean distance, and recedes farther from it. When she is nearest, she attracts strongest, and so raises the tides most; the contrary happens when she is farthest, because of her weaker attraction. When both luminaries are in the equator, and the Moon *in Perigeo*, or at her least distance from the Earth, she raises the tides highest of all, especially at her conjunction and opposition, both because the equatorial parts have the greatest centrifugal force, from their describing the largest circle, and from the concurring actions of the Sun and Moon. At the change, the attractive forces of the Sun and Moon being united, they diminish the gravity of the waters under the Moon, and their gravity on the opposite side is diminished by means of a greater centrifugal force. At the full, whilst the Moon raises the tide under and opposite to her, the Sun acting in the same line, raises the tide under and opposite to him; whence their conjoint effect is the same as at the change, and in both cases occasion what we call the *spring tides:* but at the quarter the Sun's action on the waters at *O* and *H* diminishes the effect of the Moon's action on the waters at *Z* and *N;* so that they rise a little under and opposite to the Sun at *O* and *H*, and fall as much under and opposite to the Moon at *Z* and *N*, making what we call the *neap tides*, because the Sun and Moon then act cross-wise to each other. But, strictly speaking, these tides happen not till some time after; because, in this, as in other cases, § 300, the actions do not produce the greatest effect when they are at the strongest, but some time afterward.

Spring and neap tides.

Plate IX. Fig. 6.

303. The Sun being nearer the Earth in winter than in summer, § 205, is of course nearer to it in February and October, than in March and September; and, therefore, the greatest tides happen not till some time after the autumnal equinox, and return a little before the vernal.

Not greatest at the equinoxes, and why.

The tides would not immediately cease upon the annihilation of the Sun and Moon.

The sea being thus put in motion, would continue to ebb and flow for several times, even though the Sun and Moon were annihilated, or their influence should cease: as if a basin of water were agitated, the water would continue to move for some time after the basin was left to stand still Or like a pendulum, which, having been put in motion by the hand, continues to make several vibrations without any new impulse.

The lunar day, what. The tides rise to unequal height in the same day, and why.

304. When the Moon is in the equator, the tides are equally high in both parts of the lunar day, or time of the Moon's revolving from the meridian to the meridian again, which is 24 hours 50 minutes. But as the Moon declines from the equator towards either pole, the tides are alternately higher and lower at places having north or south latitude. For one of the highest elevations, which is that under the Moon, follows her towards the pole to which she is nearest, and the other declines towards the opposite pole; each elevation describing parallels as far distant from the equator, on opposite sides, as the Moon declines from it to either side; and, consequently, the parallels described by these elevations of the water are twice as many degrees from one another, as the Moon is from the equator, increasing their distance as the Moon increases her declination, till it be at the greatest, when the said parallels are, at a mean state, 47 degrees from one another: and, on that day, the tides are most unequal in their heights. As the Moon returns toward the equator, the parallels described by the opposite elevations approach towards each other, until the Moon comes to the equator, and then they coincide. As the Moon declines toward the opposite pole, at equal distances, each elevation describes the same parallel in the other part of the lunar day, which its opposite elevation described before. Whilst the Moon has north declination, the greatest tides in the northern hemisphere are when she is above the horizon; and the reverse whilst her declination is south. Let *N E S Q* be the Earth, *N C S* its axis, *E Q* the equator, *T* ♋ the tropic of Cancer, *t* ♑ the tropic of Capricorn, *a b* the arctic circle, *c d* the antarctic, *N* the north pole, *S* the south pole, *M* the Moon, *F* and *G* the two eminencies of water, whose lowest parts are at *a* and *d* (Fig. 3), at *N* and *S* (Fig.

Plate IX. Fig. 3, 4, 5.

4), and at *b* and *c* (Fig 5), always 90° from the highest. Now, when the Moon is in her greatest north declination at *M*, the highest elevation *G* under her, is on the tropic of Cancer, *T* ♋, and the opposite elevation *F* on the tropic of Capricorn *t* ♑; and these two elevations describe the tropics by the Earth's diurnal rotation. All places in the northern hemisphere *E N Q* have the highest tides when they come into the position *b* ♋ *Q*, under the Moon, and the lowest tides when the Earth's diurnal rotation carries them into the position *a T E*, on the side opposite to the Moon; the reverse happens at the same time in the southern hemisphere *E S Q*, as is evident to sight. The axis of the tides *a C d*, has now its poles *a* and *d* (being always 90° from the highest elevations) in the arctic and antarctic circles; and, therefore, it is plain, that at these circles there is but one tide of flood, and one of ebb, in the lunar day. For, when the point *a* revolves half round to *b*, in 12 lunar hours, it has a tide of flood, but when it comes to the same point *a* again in 12 hours more, it has the lowest ebb. In 7 days afterwards, the Moon *M* comes to the equinoctial circle, and is over the equator *E Q*, when both elevations describe the equator, and in both hemispheres, at equal distances from the equator, the tides are equally high in both parts of the lunar day. The whole phenomena being reversed, when the Moon has south declination, to what they were when her declination was north, require no farther description.

Plate IX. Fig. 3.

Fig 4.

Fig 5.

305 In the three last-mentioned figures, the Earth is orthographically projected on the plane of the meridian; but in order to describe a particular phenomenon, we now project it on the plane of the ecliptic. Let *H Z O N* be the Earth and Sea, *F E D* the equator, *T* the tropic of Cancer, *C* the arctic circle, *P* the north pole, and the curves 1, 2, 3, &c. 24 meridians, or hour-circles, intersecting each other in the poles; *A G M* is the Moon's orbit, *S* the Sun, *M* the Moon, *Z* the water elevated under the Moon, and *N* the opposite equal elevation. As the lowest parts of the water are always 90° from the highest, when the Moon is in either of the tropics (as at *M*) the elevation *Z* is on the tropic of Capricorn, and the opposite elevation *N* on the tropic of Cancer, the low-

Fig 6.

When both tides are equally high in the same day they arrive at unequal intervals of time; and *vice versa*.

water circle *H C O* touches the polar circles at *C*; and the high-water circle *E T P* 6 goes over the poles at *P*, and divides every parallel of latitude into two equal segments. In this case the tides upon every parallel are alternately higher and lower, but they return in equal times: the point *T*, for example, on the tropic of Cancer (where the depth of the tide is represented by the breadth of the dark shade), has a shallower tide of flood at *T*, than when it revolves half round from thence to 6, according to the order of the numeral figures; but it revolves as soon from 6 to *T*, as it did from *T* to 6. When the Moon is in the equinoctial, the elevations *Z* and *N* are transferred to the equator at *O* and *H*, and the high and low-water circles are got into each other's former places; in which case the tides return in unequal times, but are equally high in parts of the lunar day; for a place at 1 (under *D*) revolving as formerly, goes sooner from 1 to 11 (under *F*) than from 11 to 1, because the parallel it describes is cut into unequal segments by the high-water circle *H C O*: but the points 1 and 11 being equidistant from the pole of the tides at *C*, which is directly under the pole of the Moon's orbit *M G A*, the elevations are equally high in both parts of the day.

306. And thus it appears, that as the tides are governed by the Moon, they must turn on the axis of the Moon's orbit, which is inclined 23½ degrees to the Earth's axis at a mean state; and, therefore, the poles of the tides must be so many degrees from the poles of the Earth, or in opposite points of the polar circles, going round these circles in every lunar day. It is true, that according to Fig. 4, when the Moon is vertical to the equator *E C Q*, the poles of the tides seem to fall in with the poles of the world *N* and *S*; but when we consider that *F G H* is under the Moon's orbit, it will appear that when the Moon is over *H*, in the tropic of Capricorn, the north pole of the tides (which can be no more than 90° from under the Moon) must be at *C* in the arctic circle, not at *P*, the north pole of the Earth; and as the Moon ascends from *H* to *G* in her orbit, the north pole of the tides must shift from *c* to *a* in the arctic circle, and the south pole as much in the antarctic.

Fig. 4.

It is not to be doubted, but that the Earth's quick rotation brings the poles of the tides nearer to the poles of the world, than they would be if the Earth were at rest, and the Moon revolved about it only once a month; for, otherwise, the tides would

be more unequal in their heights, and times of their returns, than we find they are. But how near the Earth's rotation may bring the poles of its axis and those of the tides together, or how far the preceding tides may affect those which follow, so as to make them keep up nearly to the same heights, and times of ebbing and flowing, is a problem more fit to be solved by observation than by theory.

307. Those who have opportunity to make observations, and choose to satisfy themselves whether the tides are really affected in the above manner by the different positions of the Moon, especially as to the unequal times of their returns, may take this general rule for knowing when they ought to be so affected. When the Earth's axis inclines to the Moon, the northern tides, if not retarded in their passage through shoals and channels, nor affected by the winds, ought to be greatest when the Moon is above the horizon, least when she is below it; and quite the reverse when the Earth's axis declines from her; but in both cases at equal intervals of time. When the Earth's axis inclines sidewise to the Moon, both tides are equally high, but they happen at unequal intervals of time. In every lunation the Earth's axis inclines once to the Moon, once from her, and twice sidewise to her, as it does to the Sun every year, because the Moon goes round the ecliptic every month, and the Sun but once in a year. In summer, the Earth's axis inclines towards the Moon when new; and, therefore, the day-tides in the north ought to be highest, and night-tides lowest about the change: at the full the reverse. At the quarters they ought to be equally high, but unequal in their returns: because the Earth's axis then inclines sidewise to the Moon. In winter the phenomena are the same at full moon as in summer at new. In autumn, the Earth's axis inclines sidewise to the Moon when new and full; therefore the tides ought to be equally high and unequal in their returns at these times. At the first quarter the tides of flood should be least when the Moon is above the horizon, greatest when she is below it, and the reverse at her third quarter. In spring, the phenomena of the first quarter answer to those of the third quarter in autumn, and *vice versa*. The nearer any time is to either of these seasons, the more the tides partake of the phenomena of these seasons; and in the middle between any two of them, the tides are at a mean state between those of both.

To know at what times we may expect the greatest and least tides

Why the tides rise higher in rivers than in the sea.

308. In open seas, the tides rise but to very small heights in proportion to what they do in wide-mouthed rivers, opening in the direction of the stream of tide. For, in channels growing narrower gradually, the water is accumulated by the opposition of the contracting bank. Like a gentle wind, little felt on an open plain, but strong and brisk in a street; especially if the wider end of the street be next the plain, and in the way of the wind.

The tides happen at all distances of the Moon from the meridian at different places, and why.

309. The tides are so retarded in their passage through different shoals and channels, and otherwise so variously affected by striking against capes and headlands, that to different places they happen at all distances of the Moon from the meridian; consequently at all hours of the lunar day. The tide propagated by the Moon in the German ocean, when she is three hours past the meridian, takes 12 hours to come from thence to London bridge, where it arrives by the time that a new tide is raised in the ocean. And, therefore, when the Moon has north declination, and we should expect the tide at London to be greatest when the Moon is above the horizon, we find it is least, and the contrary when she has south declination. At several places it is high water 3 hours before the Moon comes to the meridian; but that tide which the Moon pushes, as it were, before her, is only the tide opposite to that which was raised by her when she was 9 hours past the opposite meridian.

The water never rises in lakes.

310. There are no tides in lakes, because they are generally so small, that when the Moon is vertical she attracts every part of them alike; and, therefore, by rendering all the water equally light, no part of it can be raised higher than another. The Mediterranean and Baltic seas have very small elevations, because the inlets by which they communicate with the ocean are so narrow, that they cannot, in so short a time, receive or discharge enough to raise or sink their surfaces sensibly.[2]

[2] It can easily be demonstrated, that the height of the tides in small seas is to their height in the main ocean, as the extent of the small sea from east to west, is to the radius of the Earth. This gives only a tide 1½ inches high for the Caspian sea. M. D'Angos observed, that the tides at Toulon on the Mediterranean rose to the height of a foot about 3½ hours after the Moon passed the meridian.—*Ed.*

311. Air being lighter than water, and the surface of the atmosphere being nearer to the Moon than the surface of the sea, it cannot be doubted that the Moon raises much higher tides in the air than in the sea. And, therefore, many have wondered why the mercury does not sink in the barometer, when the Moon's action on the particles of air makes them lighter as she passes over the meridian. But we must consider, that as these particles are rendered lighter, a greater number of them is accumulated, until the deficiency of gravity be made up by the height of the column, and then there is an *equilibrium*, and, consequently, an equal pressure upon the mercury as before; so that it cannot be affected by the aerial tides.[3]

The Moon raises tides in the air.

Why the mercury in the barometer is not affected by the aerial tides.

CHAP. XVIII.

OF ECLIPSES—THEIR NUMBER AND PERIODS—A LARGE CATALOGUE OF ANCIENT AND MODERN ECLIPSES.

312. EVERY planet and satellite is illuminated by the Sun, and casts a shadow towards that point of the heavens which is opposite to the Sun. This shadow is nothing but a privation of light in the space hid from the Sun by the opaque body that intercepts his rays

A shadow, what.

313. When the Sun's light is so intercepted by the Moon, that to any place of the Earth the Sun appears partly or wholly covered, he is said to undergo an eclipse, though properly speaking it is only an eclipse of that part of the Earth where the Moon's shadow or penumbra[1] falls. When the Earth comes between the Sun and Moon, the Moon falls into the Earth's shadow; and, having no light

Eclipses of the Sun and Moon, what.

[3] The existence of aerial tides has been rendered very probable by the observations of Professor Toaldo of Padua. In a register of the barometer, kept for thirty years, he added together all the heights of the mercury when the Moon was in syzigy, when she was in quadrature, and when she was in the apogeal and perigeal points of her orbit. The apogeal exceeded the perigeal heights by 14 inches, and the heights in syzigy exceeded those in quadrature by 11 inches. The difference in these heights is sufficiently great to shew that the air is accumulated and compressed by the attraction of the Moon.—*Ed.*

[1] The penumbra is a faint kind of shadow all around the perfect shadow of the planet or satellite, and will be more fully explained by and by.

of her own, she suffers a real eclipse from the interception of the Sun's rays. When the Sun is eclipsed to us, the Moon's inhabitants on the side next the Earth (if any such there be) see her shadow like a dark spot travelling over the Earth, about twice as fast as its equatorial parts move, and the same way as they move. When the Moon is in an eclipse, the Sun appears eclipsed to her, total to all those parts on which the Earth's shadow falls, and of as long continuance as they are in the shadow.

A proof that the Earth and Moon are globular bodies.

314. That the Earth is spherical (for the hills take off no more from the roundness of the Earth, than grains of dust do from the roundness of a common globe), is evident from the figure of its shadow on the Moon, which is always bounded by a circular line, although the Earth is incessantly turning its different sides to the Moon, and very seldom shews the same side to her in different eclipses, because they seldom happen at the same hours. Were the Earth shaped like a round flat plate, its shadow would only be circular when either of its sides directly faced the Moon; and more or less elliptical as the Earth happened to be turned more or less obliquely towards the Moon when she is eclipsed. The Moon's different phases prove her to be round (§ 254); for, as she keeps still the same side towards the Earth, if that side were flat, as it appears to be, she would never be visible from the third quarter to the first; and from the first quarter to the third, she would appear as round as when we say she is full: because at the end of her first quarter, the Sun's light would come as suddenly on all her side next the Earth, as it does on a flat wall, and go off as abruptly at the end of her third quarter.

And that the Sun is much bigger than the Earth, and the Moon much less.

315. If the Earth and Sun were equally big, the Earth's shadow would be infinitely extended, and all of the same bulk; and the planet Mars, in either of its nodes, and opposite to the Sun, would be eclipsed in the Earth's shadow. Were the Earth bigger than the Sun, its shadow would increase in bulk the farther it extended, and would eclipse the great planets Jupiter and Saturn, with all their moons, when they were opposite to the Sun. But as Mars, in opposition, never falls into the Earth's shadow, although he is not then above 42,000,000 of miles from the Earth, it is plain that the Earth is much

less than the Sun; for, otherwise, its shadow could not end in a point at so small a distance. If the Sun and Moon were equally big, the Moon's shadow would go on to the Earth with an equal breadth, and cover a portion of the Earth's surface more than 2000 miles broad, even if it fell directly against the Earth's centre, as seen from the Moon, and much more if it fell obliquely on the Earth: but the Moon's shadow is seldom 150 miles broad at the Earth, unless when it falls very obliquely on the Earth, in total eclipses of the Sun. In annular eclipses, the Moon's real shadow ends in a point at some distance from the Earth. The Moon's small distance from the Earth, and the shortness of her shadow, prove her to be less than the Sun. And as the Earth's shadow is large enough to cover the Moon, if her diameter were 3 times as large as it is (which is evident from her long continuance in the shadow when she goes through its centre), it is plain that the Earth is much bigger than the Moon.

The primary planets never eclipse one another.

316. Though all opaque bodies on which the Sun shines have their shadows, yet such is the bulk of the Sun, and the distances of the planets, that the primary planets can never eclipse one another. A primary can eclipse only its secondary, or be eclipsed by it; and never but when in opposition or conjunction with the Sun. The primary planets are very seldom in these positions, but the Sun and Moon are so every month: whence one may imagine that these two luminaries should be eclipsed every month. But there are few eclipses in respect of the number of new and full moons; the reason of which we shall now explain.

Why there are so few eclipses.

317. If the Moon's orbit were coincident with the plane of the ecliptic, in which the Earth always moves, and the Sun appears to move, the Moon's shadow would fall upon the Earth at every change, and eclipse the Sun to some parts of the Earth. In like manner the Moon would go through the middle of the Earth's shadow, and be eclipsed at every full; but with this difference, that she would be totally darkened for above an hour and a half; whereas the Sun never was above four minutes totally eclipsed by the interposition of the Moon. But one half of the Moon's orbit is elevated $5\frac{1}{3}$ degrees above the ecliptic, and the other half as much depressed below it: consequently the Moon's orbit intersects the ecliptic in two opposite points, called *the Moon's Nodes*, as has been already taken

The Moon's nodes.

notice of, § 288. When these points are in a right line with the centre of the Sun at new or full moon, the Sun, Moon, and Earth are all in a right line; and if the Moon be then new, her shadow falls upon the Earth; if full, the Earth's shadow falls upon her. When the Sun and Moon are more than 17 degrees from either of the nodes at the time of conjunction, the Moon is then generally too high or too low in her orbit, to cast any part of her shadow upon the Earth. And when the Sun is more than 12 degrees from either of the nodes at the time of full moon, the Moon is generally too high or too low in her orbit to go through any part of the Earth's shadow; and in both these cases there will be no eclipse. But when the Moon is less than 17 degrees from either node at the time of conjunction, her shadow or penumbra falls more or less upon the Earth, as she is more or less within this limit.[2] And when she is less than 12 degrees from either node at the time of opposition, she goes through a greater or less portion of the Earth's shadow as she is more or less within this limit. Her orbit contains 360 degrees, of which 17, the limit of solar eclipses on either side of the nodes, and 12, the limit of lunar eclipses, are but small portions: and as the Sun commonly passes by the nodes but twice in a year, it is no wonder that we have so many new and full moons without eclipses.

Limits of eclipses.

To illustrate this, let *A B C D* be the *ecliptic*, *R S T U* a circle lying in the same plane with the ecliptic, and *V W X Y* the *Moon's orbit*, all thrown into an oblique view, which gives them an elliptical shape to the eye. One half of the Moon's orbit, as *V W X*, is always below the ecliptic, and the other half *X Y V* above it. The points *V* and *X*, where the Moon's orbit intersects the circle *R S T U*, which lies even with the ecliptic, are the *Moon's nodes*; and a right line, as *X E V*, drawn, from one to the other, through the Earth's centre, is called the *Line of the Nodes*, which is carried almost parallel to itself round the Sun in a year.

Plate X. Fig. 1.

Line of the nodes.

If the Moon moved round the Earth in the orbit *R S T U*, which is coincident with the plane of the ecliptic, her shadow would fall upon the Earth every time she is in conjunction with the Sun, and at every opposition she would go through the

[2] This admits of some variation; for, in *apogeal* eclipses, the solar limit is but 16$\frac{1}{2}$ degrees; and in *perigeal* eclipses it is 18$\frac{1}{3}$. When the full Moon is in her *apogee*, she will be eclipsed if she be within 10$\frac{1}{2}$ degrees of the node; and when she is full in her *perigee*, she will be eclipsed if she be within 12$\frac{1}{12}$ degrees of the node.

Earth's shadow. Were this the case, the Sun would be eclipsed at every change, and the Moon at every full, as already mentioned.

But although the Moon's shadow *N* must fall upon the Earth at *a*, when the Earth is at *E*, and the Moon in conjunction with the Sun at *i*, because she is then very near one of her nodes; and at her opposition *n* she must go through the Earth's shadow *I*, because she is then near the other node; yet, in the time that she goes round the Earth to her next change, according to the order of the letters *X Y V W*, the Earth advances from *E* to *e*, according to the order of the letters *E F G H*, and the line of the nodes *V E X* being carried nearly parallel to itself, brings the point *f* of the Moon's orbit in conjunction with the Sun at that next change, and then the Moon being at *f*, is too high above the ecliptic to cast her shadow on the Earth: and as the Earth is still moving forward, the Moon, at her next opposition will be at *g*, too far below the ecliptic to go through any part of the Earth's shadow; for by that time the point *g* will be at a considerable distance from the Earth as seen from the Sun.

When the Earth comes to *F*, the Moon in conjunction with the Sun *Z* is not at *k*, in a plane coincident with the ecliptic, but above it at *Y* in the highest part of her orbit: and then the point *b* of her shadow *O* goes far above the Earth (as in Fig. 2, which is an edge view of Fig. 1). The Moon at her next opposition is not at *o* (Fig. 1), but at *W*, where the Earth's shadow goes far above her (as in Fig. 2). Fig. 1, 2. In both these cases the line of the nodes *V F X* (Fig 1) is about 90 degrees from the Sun, and both luminaries are as far as possible from the limits of eclipses.

When the Earth has gone half round the ecliptic from *E* to *G*, the line of the nodes *V G X* is nearly, if not exactly directed towards the Sun at *Z*; and then the new moon *l* casts her shadow *P* on the Earth *G*; and the full moon *p* goes through the Earth's shadow *L*; which brings on eclipses again, as when the Earth was at *E*.

When the Earth comes to *H*, the new Moon falls not at *m* in a plane coincident with the ecliptic *C D*, but at *W* in her orbit below it: and then her shadow *Q* (see Fig. 2) goes far below the Earth. At the next full she is not at *q* (Fig. 1), but at *Y* in her orbit $5\frac{1}{3}$ degrees above *q*, and at her greatest height above the ecliptic *C D*; being then as far as possible, at any opposition, from the Earth's shadow *M* (as in Fig. 2).

So, when the Earth is at *E* and *G*, the Moon is about her nodes at new and full; and in her greatest *north* and *south declination* (or latitude, as it is generally called) from the ecliptic at her quarters: but when the Earth is at *F* or *H*, the Moon is in her greatest *north* and *south declination* from the ecliptic at new and full, and in the *nodes* about her quarters.

Plate X. Fig. 1. The Moon's ascending and descending node.

318. The point *X* where the Moon's orbit crosses the ecliptic is called *the Ascending node*, because the Moon ascends from it above the ecliptic: and the opposite point of intersection *V* is called *the Descending node*, because the Moon descends from it below the ecliptic. When the Moon is at *Y* in the highest point of her orbit, she is in her greatest *north latitude*; and when she is at *W* in the lowest point of her orbit, she is in her greatest *south latitude*.

Her north and south latitude.

The nodes have a retrograde motion.

319. If the line of the nodes, like the Earth's axis, was carried parallel to itself round the Sun, there would be just half a year between the conjunctions of the Sun and nodes. But the nodes shift backward, or contrary to the Earth's annual motion, 19¼ degrees every year; and, therefore, the same node comes round to the Sun 19 days sooner every year than on the year before. Consequently, from the time that the ascending node *X* (when the Earth is at *E*) passes by the Sun as seen from the Earth, it is only 173 days (not half a year) till the descending node *V* passes by him. Therefore, in whatever time of the year we have eclipses of the luminaries about either node, we may be sure that in 173 days afterwards we shall have eclipses about the other node. And when at any time of the year the line of the nodes is in the situation *V G X*, at the same time next year it will be in the situation *r G s*; the ascending node having gone backward, that is, contrary to the order of signs, from *X* to *s*, and the descending node from *V* to *r*, each 19⅓ degrees. At this rate the nodes shift through all the signs and degrees of the ecliptic in 18 years and 225 days; in which time there would always be a regular period of eclipses, if any complete number of lunations were finished without a fraction. But this never happens; for if both the Sun and Moon should start from a line of conjunction with either of the nodes in any point of the ecliptic, the Sun would

Which brings on the eclipses sooner every year than they would be if the nodes had not such a motion.

perform 18 annual revolutions and 222° over and above, and the Moon 230 lunations, and 85 degrees of the 231st, by the time the node came round to the same point of the ecliptic again: so that the Sun would then be 138 degrees from the node, and the Moon 85 degrees from the Sun.

320. But in 223 mean lunations, after the Sun, Moon, and nodes, have been once in a line of conjunction, they return so nearly to the same state again, as that the same node, which was in conjunction with the Sun and Moon at the beginning of the first of these lunations, will be within 28′ 12″ of a degree of a line of conjunction with the Sun and Moon again, when the last of these lunations is completed. And, therefore, in that time there will be a regular period of eclipses, or return of the same eclipse for many ages. In this period (which was first discovered by the Chaldeans) there are 18 Julian years 11 days 7 hours 43 minutes 20 seconds, when the last day of February in leap-years is four times included; but when it is five times included, the period consists of only 18 years 10 days 7 hours 43 minutes 20 seconds.[3] Consequently, if to the mean time of any eclipse, either of the Sun or Moon, you add 18 Julian years 11 days 7 hours 43 minutes 20 seconds, when the last day of February in leap-years comes in four times, or a day less when it comes in five times, you will have the mean time of the return of the same eclipse.

A period of eclipses.

But the falling back of the line of conjunctions, or oppositions of the Sun and Moon 28′ 12″ with respect to the line of the nodes in every period, will wear it out in process of time; and after that it will not return again in less than 12,492 years. These eclipses of the Sun, which happen about the ascending node, and begin to come in at the north pole of the Earth, will go a little southerly at each return, till they go quite off the Earth at the south pole; and those which happen about the descending node, and begin to come in at the south pole of the Earth, will go a little northerly at each return, till at last they quite leave the Earth at the north pole.

To exemplify this matter, we shall first consider the Sun's eclipse, March 21st old style (April 1st new style) A. D. 1764,

[3] By computing this period from the new solar tables of De Lambre, founded on Dr. Maskelyne's observations, and from the tables of Mayer as improved by Mason, it will amount only to 18 years 11 days 7 hours 42 minutes 31 seconds, and the Sun's distance from the Moon's node will be 28′ 10″.—*Ed.*

according to its mean revolutions, without equating the times, or the Sun's distance from the node, and then according to its true equated times.

This eclipse fell in the open space at each return, quite clear of the Earth, ever since the creation till A. D. 1295, June 13th old style, at 12 hours 52 minutes 59 seconds *post meridiem*, when the Moon's shadow first touched the Earth at the north pole, the Sun being then 17° 48′ 27″ from the ascending node. —In each period since that time, the Sun has come 28′ 12″ nearer and nearer the same node, and the Moon's shadow has therefore gone more and more southerly. In the year 1962, July 18th old style, at 10 hours 36 minutes 21 seconds *p. m.* when the same eclipse will have returned 38 times, the Sun will be only 24′ 45″ from the ascending node, and the centre of the Moon's shadow will fall a little northward of the Earth's centre. —At the end of the next following period, A. D. 1980, July 28th old style, at 18 hours 19 minutes 41 seconds *p. m.* the Sun will have receded back 3′ 27″ from the ascending node, and the Moon will have a very small degree of southern latitude, which will cause the centre of her shadow to pass a very small matter south of the Earth's centre. After which, in every following period, the Sun will be 28′ 12″ farther back from the ascending node than in the period last before; and the Moon's shadow will go still farther and farther southward, until September 12th old style, at 23 hours 46 minutes 22 seconds *p. m.* A. D. 2665; when the eclipse will have completed its 77th periodical return, and will go quite off the Earth at the south pole (the Sun being then 17° 55′ 22″ back from the node), and it cannot come in at the north pole, so as to begin the same course over again, in less than 12,492 years afterwards. And such will be the case of every other eclipse of the Sun: for as there is about 18 degrees on each side of the node within which there is a possibility of eclipses, their whole revolution goes through 36 degrees about that node, which taken from 360 degrees, leaves remaining 324 degrees for the eclipses to travel *in expansum*. And as this 36 degrees is not gone through in less than 77 periods, which takes up 1388 years, the remaining 324 degrees cannot be so gone through in less than 12,492 years. For, as 36 is to 1388, so is 324 to 12,492.

321. In order to shew both the mean and true times of the returns of this eclipse, through all its periods, together with the

mean anomalies of the Sun and Moon, at each return, and the mean and true distances of the Sun from the Moon's ascending node, and the Moon's true latitude at the true time of each new moon, I have calculated the following tables for the sake of those who may choose to project this eclipse at any of its returns, according to the rules laid down in the 15th chapter, and have thereby taken by much the greatest part of the trouble off their hands. All the times are according to the old style, for the sake of a regularity which, with respect to the nominal days of the months, does not take place in the new: but by adding the day's difference of style, they are reduced to the times which agree with the new style.

According to the mean (or supposed equable) motions of the Sun, Moon, and nodes, the Moon's shadow in this eclipse would have first touched the Earth at the north pole, on the 13th of June A. D. 1295, at 12 hours 52 minutes 59 seconds past noon on the meridian of London, and would quite leave the Earth at the south pole on the 12th of September, A. D. 2665, at 23 hours 46 minutes 22 seconds past noon, at the completion of its 77th period, as shewn by the first and second tables.

But, on account of the true (or unequable) motions of the Sun, Moon, and nodes, the first coming-in of this eclipse, at the north pole of the Earth, was on the 24th of June A. D. 1313, at 3 hours 57 minutes 3 seconds past noon; and it will finally leave the Earth at the south pole on the 31st of July A. D. 2593, at 10 hours 25 minutes 31 seconds past noon at the completion of its 72d period, as shewn by the third and fourth tables. So that the true motions do not only alter the true times from the mean, but they also cut off five periods from those of the mean returns of this eclipse,

TABLE I. The mean Time of New Moon, with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Moon's Ascending Node, at the mean Time of each periodical Return of the Sun's Eclipse, March 21, 1764, from its first coming upon the Earth since the Creation, till it falls right against the Earth's centre, according to the Old Style.

Periodical Returns.	Years of Christ.	Mean Time of New Moon.					Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
		Month.	D.	H.	M.	S.	s.	°	'	"	s.	°	'	"	s.	°	'	"
0	1277	June	2	5	9	39	11	17	57	41	1	26	31	12	0	18	16	10
1	1295	June	13	12	52	59	11	28	27	38	1	23	40	19	0	17	48	27
2	1313	June	23	20	36	19	0	8	57	35	1	20	48	56	0	17	20	15
3	1331	July	5	4	19	30	0	19	27	32	1	17	57	35	0	16	52	2
4	1349	July	15	12	2	59	0	29	57	29	1	15	6	10	0	16	23	50
5	1367	July	26	19	46	19	1	10	27	26	1	12	14	47	0	15	55	37
6	1385	Aug.	6	3	29	39	1	20	57	23	1	9	23	24	0	15	27	25
7	1403	Aug.	17	11	12	59	2	1	27	20	1	6	32	1	0	14	59	12
8	1421	Aug.	27	18	56	19	2	11	57	17	1	3	40	38	0	14	31	0
9	1439	Sept.	8	2	39	39	2	22	27	14	1	0	49	15	0	14	2	47
10	1457	Sept.	18	10	2	59	3	2	57	11	0	27	57	52	0	13	34	35
11	1475	Sept.	29	18	6	19	3	13	27	8	0	25	6	29	0	13	6	22
12	1493	Oct.	10	1	49	39	3	23	57	5	0	22	15	6	0	12	38	10
13	1511	Oct.	21	9	32	59	4	4	27	2	0	19	23	43	0	12	9	57
14	1529	Oct.	31	17	16	19	4	14	56	59	0	16	32	20	0	11	41	45
15	1547	Nov.	12	0	59	40	4	25	26	56	0	13	40	57	0	11	13	32
16	1565	Nov.	22	8	43	0	5	5	56	53	0	10	49	34	0	10	45	20
17	1583	Dec.	3	16	26	20	5	16	26	50	0	7	58	9	0	10	17	7
18	1601	Dec.	14	0	9	40	5	26	56	47	0	5	6	48	0	9	48	55
19	1619	Dec.	25	7	53	0	6	7	26	44	0	2	15	25	0	9	20	42
20	1638	Jan.	4	15	36	20	6	17	56	41	11	29	24	2	0	8	52	30
21	1656	Jan.	15	23	19	40	6	28	26	38	11	26	32	39	0	8	24	17
22	1674	Jan.	26	7	3	0	7	8	56	35	11	23	41	14	0	7	56	5
23	1692	Feb.	6	14	46	20	7	19	26	32	11	20	49	53	0	7	27	52
24	1710	Feb.	16	22	29	40	7	29	56	29	11	17	58	30	0	6	59	40
25	1728	Feb.	28	6	13	0	8	10	26	26	11	15	7	7	0	6	31	27
26	1746	March	10	13	56	20	8	20	56	23	11	12	15	44	0	6	3	15
27	1764	March	20	21	39	40	9	1	26	20	11	9	24	21	0	5	35	2
28	1782	April	1	5	23	0	9	11	56	17	11	6	32	58	0	5	6	50
29	1800	April	11	13	6	29	9	22	26	14	11	3	41	35	0	4	38	37
30	1818	April	22	20	49	40	10	2	56	11	11	0	50	12	0	4	10	25
31	1836	May	3	4	33	0	10	13	26	8	10	27	58	49	0	3	42	12
32	1854	May	14	12	16	29	10	23	56	5	10	25	7	26	0	3	14	0
33	1872	May	24	19	59	40	11	4	26	2	10	22	16	3	0	2	45	47
34	1890	June	5	3	43	0	11	14	55	59	10	19	24	40	0	2	17	35
35	1908	June	15	11	26	20	11	25	25	56	10	16	33	17	0	1	49	22
36	1926	June	26	19	9	40	0	5	55	53	10	13	41	54	0	1	21	10
37	1944	July	7	2	53	0	0	16	25	50	10	10	50	31	0	0	52	57
38	1962	July	18	10	36	21	0	26	55	47	10	7	59	8	0	0	24	45

TABLE II. The mean Time of New Moon, with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Moon's Ascending Node, at the Mean Time of each periodical Return of the Sun's Eclipse, March 21, 1764, from the mean Time of its falling right against the Earth's Centre, till it finally leaves the Earth, according to the Julian or Old Style.

Periodical Returns.	Years of Christ	Mean Time of New Moon.					Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
		Month.	D.	H.	M.	S.	s.	°	′	″	s.	°	′	″	s.	°	′	″
39	1980	July	28	18	19	41	1	7	25	44	10	5	7	45	11	29	56	33
40	1998	Aug.	9	2	3	1	1	17	55	41	10	2	16	22	11	29	28	20
41	2016	Aug.	19	9	46	21	1	28	25	38	9	29	24	59	11	29	0	8
42	2034	Aug.	30	17	29	41	2	8	55	36	9	26	33	36	11	28	31	55
43	2052	Sept.	10	1	13	1	2	19	25	33	9	23	42	13	11	28	3	43
44	2070	Sept.	21	8	56	21	2	29	55	32	9	20	50	50	11	27	35	30
45	2088	Oct.	1	16	39	41	3	10	25	27	9	17	59	27	11	27	7	18
46	2106	Oct.	13	0	23	1	3	20	55	24	9	15	8	4	11	26	39	5
47	2124	Oct.	23	8	6	21	4	1	25	21	9	12	16	41	11	26	10	53
48	2142	Nov.	3	15	49	41	4	11	55	18	9	9	25	18	11	25	42	40
49	2160	Nov.	13	23	31	1	4	22	25	15	9	6	33	56	11	25	14	28
50	2178	Nov.	25	7	16	21	5	2	55	12	9	3	42	33	11	24	46	15
51	2196	Dec.	5	14	59	41	5	13	25	9	9	0	51	10	11	24	18	3
52	2214	Dec.	16	22	43	1	5	23	55	7	8	27	59	47	11	23	49	50
53	2232	Dec.	27	6	26	21	6	4	25	4	8	25	8	24	11	23	21	38
54	2251	Jan.	7	14	9	41	6	14	55	1	8	22	17	1	11	22	53	25
55	2269	Jan.	17	21	53	1	6	25	24	58	8	19	25	38	11	22	15	13
56	2287	Jan.	29	5	36	21	7	5	54	55	8	16	31	15	11	21	57	0
57	2305	Feb.	8	13	19	41	7	16	24	52	8	13	42	52	11	21	28	48
58	2323	Feb.	19	21	3	1	7	26	54	49	8	10	51	29	11	21	0	35
59	2341	March	2	4	46	21	8	7	24	46	8	8	0	6	11	20	32	23
60	2359	March	13	12	29	42	8	17	54	43	8	5	8	43	11	20	4	10
61	2377	March	23	20	13	2	8	28	24	40	8	2	17	20	11	19	35	58
62	2395	April	4	3	56	22	9	8	54	37	7	29	25	57	11	19	7	45
63	2413	April	14	11	39	42	9	19	24	34	7	26	34	34	11	18	39	33
64	2431	April	25	19	23	2	9	29	54	31	7	23	43	11	11	18	11	20
65	2449	May	6	3	6	22	10	10	24	28	7	20	51	48	11	17	43	8
66	2467	May	17	10	49	42	10	20	54	25	7	18	0	25	11	17	14	54
67	2485	May	27	18	33	2	11	1	24	22	7	15	9	2	11	16	46	43
68	2503	June	8	2	16	22	11	11	54	19	7	12	17	39	11	16	18	31
69	2521	June	18	9	59	42	11	22	24	17	7	9	26	16	11	15	50	18
70	2539	June	29	17	43	2	0	2	54	14	7	6	34	53	11	15	22	6
71	2557	July	10	1	26	22	0	13	24	11	7	3	43	30	11	14	53	54
72	2575	July	21	9	9	42	0	23	54	8	7	0	52	7	11	14	25	41
73	2593	July	31	16	53	2	1	4	24	5	6	28	0	44	11	13	57	28
74	2611	Aug.	12	0	36	22	1	14	54	2	6	25	9	21	11	13	29	16
75	2629	Aug.	22	8	19	42	1	25	23	59	6	22	17	58	11	13	1	3
76	2647	Sept.	2	16	3	2	2	5	53	56	6	19	26	35	11	12	32	51
77	2665	Sept.	12	23	46	22	2	16	23	53	6	16	35	12	11	12	4	38

Table III. The true Time of New Moon, with the Sun's true Distance from the Moon's Ascending Node, and the Moon's true Latitude, at the true Time of each periodical Return of the Sun's Eclipse, March 21, Old Style, A. D. 1764, from the Time of its first coming upon the Earth since the Creation, till it falls right against the Earth's Centre.

Periodical Returns.	Years of Christ.	True Time of New Moon.					Sun's true dist. from the Node.				Moon's true Latitude, North.			
		Month.	D.	H.	M.	S.	S.	°	′	″	°	′	″	North.
0	1295	June	13	21	54	32	0	18	40	54	1	33	45	N. A.
1	1313	June	24	3	57	3	0	17	20	22	1	29	34	N. A.
2	1331	July	5	10	42	8	0	16	29	35	1	25	20	N. A.
3	1349	July	15	17	14	15	0	15	34	18	1	20	45	N. A.
4	1367	July	26	23	49	24	0	14	46	8	1	16	39	N. A.
5	1385	Aug.	6	6	41	17	0	13	59	43	1	12	43	N. A.
6	1403	Aug.	17	13	32	19	0	13	16	44	1	9	3	N. A.
7	1421	Aug.	27	20	30	17	0	12	37	4	1	5	42	N. A.
8	1439	Sept.	8	3	51	46	0	12	1	54	1	2	41	N. A.
9	1457	Sept.	18	10	23	11	0	11	30	27	0	58	53	N. A.
10	1475	Sept.	29	17	57	7	0	11	3	56	0	57	43	N. A.
11	1493	Oct.	10	1	44	3	0	10	41	55	0	55	49	N. A.
12	1511	Oct.	21	9	29	53	0	10	25	11	0	54	28	N. A.
13	1529	Oct.	31	17	9	18	0	10	11	27	0	53	12	N. A.
14	1547	Nov.	12	0	51	25	0	10	1	10	0	52	19	N. A.
15	1565	Nov.	22	8	54	56	0	9	52	49	0	51	46	N. A.
16	1583	Dec.	3	16	48	17	0	9	48	4	0	51	11	N. A.
17	1601	Dec.	14	0	51	5	0	9	43	42	0	50	49	N. A.
18	1619	Dec.	25	8	54	59	0	9	40	23	0	50	31	N. A.
19	1638	Jan.	4	16	56	1	0	9	34	57	0	50	3	N. A.
20	1656	Jan.	16	0	54	41	0	9	29	24	0	49	57	N. A.
21	1674	Jan.	26	8	48	24	0	9	19	44	0	48	44	N. A.
22	1692	Feb.	6	16	36	28	0	9	8	58	0	47	49	N. A.
23	1710	Feb.	17	0	8	37	0	8	54	20	0	46	44	N. A.
24	1728	Feb.	28	7	43	40	0	8	34	53	0	44	52	N. A.
25	1746	March	10	15	14	33	0	8	10	38	0	42	46	N. A.
26	1764	March	20	22	30	26	0	7	42	14	0	40	18	N. A.
27	1782	April	1	5	37	4	0	7	9	27	0	37	28	N. A.
28	1800	April	11	12	36	38	0	6	35	30	0	34	31	N. A.
29	1818	April	22	19	27	34	0	5	51	48	0	30	43	N. A.
30	1836	May	3	2	12	7	0	5	5	5	0	26	40	N. A.
31	1854	May	14	8	50	40	0	4	19	45	0	22	42	N. A.
32	1872	May	24	15	28	15	0	3	26	3	0	18	1	N. A.
33	1890	June	4	22	8	0	0	2	35	5	0	13	34	N. A.
34	1908	June	15	4	38	23	0	1	41	43	0	8	54	N. A.
35	1926	June	26	11	13	5	0	0	47	38	0	4	10	N. A.

On account of the differences between the mean and true new Moons, and between the Sun's mean and true distances from the node, the Moon's shadow falls even with the Earth's centre two periods sooner in this Table than in the first.

Table IV. The true Time of New Moon, with the Sun's true Distance from the Moon's Ascending Node, and the Moon's true Latitude at each periodical Return of the Sun's Eclipse, March 21, Old Style, A. D. 1764, *from its falling right against the Earth's Centre, till it finally leaves the Earth.*

Periodical Returns.	Years of Christ.	True Time of New Moon.					Sun's true Dist. from the Node.				Moon's true Latitude South.			
		Month.	D.	H.	M.	S.	S.	°	′	″	°	′	″	South.
36	1944	July	6	17	50	35	11	29	55	28	0	0	24	S. A.
37	1962	July	18	0	31	38	11	29	2	33	0	5	2	S. A.
38	1980	July	28	7	18	53	11	28	11	32	0	9	29	S. A.
39	1998	Aug.	8	14	12	22	11	27	26	41	0	13	25	S. A.
40	2016	Aug.	18	21	14	53	11	26	42	16	0	17	18	S. A.
41	2034	Aug.	30	4	25	45	11	26	2	0	0	20	48	S. A.
42	2052	Sept.	9	11	45	17	11	25	26	46	0	23	53	S. A.
43	2070	Sept.	20	19	17	26	11	24	55	4	0	26	39	S. A.
44	2088	Oct.	1	2	57	8	11	24	27	43	0	28	58	S. A.
45	2106	Oct.	12	10	47	39	11	24	4	38	0	31	2	S. A.
46	2124	Oct.	22	18	37	40	11	23	48	28	0	32	26	S. A.
47	2142	Nov.	3	2	56	19	11	23	35	11	0	33	53	S. A.
48	2160	Nov.	13	11	11	20	11	23	22	22	0	34	42	S. A.
49	2178	Nov.	24	19	36	14	11	23	18	57	0	35	0	S. A.
50	2196	Dec.	5	4	4	9	11	23	14	40	0	35	22	S. A.
51	2214	Dec.	16	12	35	48	11	23	10	43	0	35	43	S. A.
52	2232	Dec.	26	20	29	9	11	23	6	47	0	36	1	S. A.
53	2251	Jan.	7	5	42	9	11	23	4	27	0	36	16	S. A.
54	2269	Jan.	17	14	14	8	11	23	0	41	0	36	35	S. A.
55	2287	Jan.	28	22	43	34	11	22	53	58	0	37	10	S. A.
56	2305	Feb.	8	7	8	30	11	22	44	44	0	37	59	S. A.
57	2323	Feb.	19	15	7	10	11	22	31	1	0	39	8	S. A.
58	2341	March	2	0	6	5	11	22	17	46	0	40	28	S. A.
59	2359	March	13	7	59	17	11	21	55	29	0	42	9	S. A.
60	2377	March	23	15	51	59	11	21	39	40	0	43	41	S. A.
61	2395	April	3	23	45	7	11	21	0	53	0	46	58	S. A.
62	2413	April	14	7	32	40	11	20	26	22	0	49	48	S. A.
63	2431	April	25	15	12	57	11	19	47	34	0	53	17	S. A.
64	2449	May	5	22	45	14	11	19	6	22	0	56	50	S. A.
65	2467	May	17	6	17	30	11	18	21	16	1	0	40	S. A.
66	2485	May	27	13	46	29	11	17	34	20	1	4	42	S. A.
67	2503	June	7	21	10	31	11	16	43	17	1	9	3	S. A.
68	2521	June	18	4	24	42	11	15	51	48	1	13	26	S. A.
69	2539	June	29	11	58	46	11	15	1	12	1	17	43	S. A.
70	2557	July	9	19	24	7	11	14	9	13	1	22	6	S. A.
71	2575	July	21	2	52	34	11	13	19	22	1	26	16	S. A.
72	2593	July	31	10	25	31	11	12	13	43	1	31	44	S. A.
73	2611	Aug.	11	17	58	39	11	11	45	13	1	36	13	S. A.

By the true motions of the Sun, Moon, and nodes, this eclipse goes off the Earth four periods sooner than it would have done by mean equable motions.

From Mr. G. Smith's Dissertation on eclipses.

'To illustrate this a little farther, we shall examine some of the most remarkable circumstances of the returns of the eclipse which happened July 14, 1748, about noon. This eclipse, after traversing the voids of space from the creation, at last began to enter the Terra Australis Incognita, about 88 years after the Conquest, which was the last of King Stephen's reign; every Chaldean[4] period it has crept more northerly, but was still invisible in Britain before the year 1622, when, on the 30th of April, it began to touch the south parts of England about 2 in the afternoon, its central appearance rising in the American South seas, and traversing Peru and the Amazon's country, through the Atlantic ocean into Africa, and setting in the Ethiopian continent, not far from the beginning of the Red sea.

'Its next visible period was after three Chaldean revolutions in 1676, on the 1st of June rising central in the Atlantic ocean, passing us about 9 in the morning, with four digits[5] eclipsed on the under limb, and setting in the gulf of Cochinchina in the East Indies.

'It being now near the solstice, this eclipse was visible the very next return in 1694, in the evening; and in two periods more, which was in 1730, on the 4th of July, was seen above half eclipsed just after sun-rise, and observed both at Wirtemberg in Germany, and Pekin in China, soon after which it went off.

'Eighteen years more afforded us the eclipse which fell on the 14th of July 1748.

'The next visible return will happen on July 25, 1766, in the evening, about four digits eclipsed; and after two periods more, on August 16, 1802, early in the morning, about five digits, the centre coming from the north frozen continent, by the capes of Norway, through Tartary, China, and Japan, to the Ladrone islands, where it goes off.

'Again, in 1820, August 26, (September 7th, N. S.) betwixt one and two, there will be another great eclipse at London, about 10 digits; but happening so near the equinox, the centre will leave every part of Britain to the west, and enter

[4] The above period of 18 years 11 days 7 hours 43 minutes 20 seconds, which was found out by the Chaldeans, and by them called *Saros*.

[5] A digit is a twelfth part of the diameter of the Sun or Moon.

Germany at Embden, passing by Venice, Naples, Grand Cairo, and set in the gulf of Bassora, near that city.

'It will be no more visible till 1874, when five digits will be obscured (the centre being now about to leave the Earth), on September 28. In 1892 the Sun will go down eclipsed at London, and again in 1928, the passage of the centre will be in the expansum, though there will be two digits eclipsed at London, October the 31st of that year; and about the year 2090 the whole penumbra will be wore off; whence no more returns of this eclipse can happen till after a revolution of 10,000 years.'

'From these remarks on the entire revolution of this eclipse, we may gather, that a thousand years, more or less (for there are some irregularities that may protract or lengthen this period 100 years) complete the whole terrestrial phenomena of any single eclipse; and since 20 periods of 54 years each, and about 33 days, comprehend the entire extent of their revolution, it is evident that the times of the returns will pass through a circuit of one year and ten months, every Chaldean period being 10 or 11 days later, and of the equable appearances about 32 or 33 days. Thus, though this eclipse happens about the middle of July, no other subsequent eclipse of this period will return to the middle of the same month again; but wear constantly each period 10 or 11 days forward, and at last appear in winter, but then it begins to cease from affecting us.

Another conclusion from this revolution may be drawn, that there will seldom be any more than two great eclipses of the Sun in the interval of this period, and these follow sometimes next return, and often at greater distances. That of 1715 returned again in 1733 very great; but this present eclipse will not be great till the arrival of 1820, which is a revolution of four Chaldean periods; so that the irregularities of their circuits must undergo new computations to assign them exactly.

'Nor do all eclipses come in at the south pole: that depends altogether on the position of the lunar nodes, which will bring in as many from the expansum one way as the other: and such eclipses will wear more southerly by degrees, contrary to what happens in the present case.

'The eclipse, for example, of 1736, in September, had its

centre in the expansum, and set about the middle of its obscurity in Britain; it will wear in at the north pole, and in the year 2600, or thereabouts, go off in the expansum on the south side of the Earth.

'The eclipses, therefore, which happened about the creation, are little more than half way yet of their ethereal circuit, and will be 4000 years before they enter the Earth any more. This grand revolution seems to have been entirely unknown to the ancients.

Why our present tables do not agree with ancient observations.

322. 'It is particularly to be noted, that eclipses which have happened many centuries ago, will not be found by our present tables to agree exactly with ancient observations, by reason of the great anomalies in the lunar motions; which appears an incontestable demonstration of the non-eternity of the universe. For it seems confirmed by undeniable proofs, that the Moon now finishes her period in less time than formerly, and will continue by the centripetal law to approach nearer and nearer the Earth, and to go sooner and sooner round it: nor will the centrifugal power be sufficient to compensate the different gravitations of such an assemblage of bodies as constitute the solar system, which would come to ruin of itself (see § 163, Note), without some new regulation and adjustment of their original motions.[6]

[6] There are two ancient eclipses of the Moon, recorded by Ptolemy from Hipparchus, which afford an undeniable proof of the Moon's acceleration. The first of these was observed at Babylon, December the 22d, in the year before Christ 383; when the Moon began to be eclipsed about half an hour before the Sun rose, and the eclipse was not over before the Moon set: but by most of our astronomical tables, the Moon was set at Babylon half an hour before the eclipse began; in which case, there could have been no possibility of observing it. The second eclipse was observed at Alexandria, September the 22d, the year before Christ 201; where the Moon rose so much eclipsed, that the eclipse must have begun about half an hour before she rose; whereas, by most of our tables, the beginning of this eclipse was not till about ten minutes after the Moon rose at Alexandria. Had these eclipses begun and ended while the Sun was below the horizon, we might have imagined, that as the ancients had no certain way of measuring time, they might have been so far mistaken in the hours, that we could not have laid any stress on the accounts given by them. But, as in the first eclipse the Moon was set, and consequently the Sun risen, before it was over; and in the second eclipse the Sun was set and the Moon not risen, till some time after it began; these are such circumstances as the observers could not possibly be mistaken in. Mr. Struyk, in the following catalogue, notwithstanding the express words of Ptolemy, puts down these two eclipses as observed at Athens; where they might have been seen as above, without any acceleration of the Moon's motion; Athens being 20° west of Babylon, and 7° west of Alexandria.

Thales's eclipse.

We are credibly informed from the testimony of the ancients, that there was a total eclipse of the Sun predicted by Thales to happen in the 4th year of the 48th Olympiad,[7] either at Sardis or Miletus in Asia, where Thales then resided. That year corresponds to the 585th year before Christ, when accordingly there happened a very signal eclipse of the Sun on the 28th of May, answering to the present 10th of that month,[8] central through North America, the south parts of France, Italy, &c. as far as Athens, or the isles in the Ægean sea; which is the farthest that even the Caroline tables carry it; and, consequently, make it invisible to any part of Asia in the total character; though I have good reason to believe that it extended to Babylon, and went down central over that city. We are not however to imagine, that it was set before it passed Sardis and the Asiatic towns, where the predictor lived; because an invisible eclipse could have been of no service to demonstrate his ability in astronomical science to his countrymen, as it could give no proof of its reality.

[7] Each Olympiad began at the time of full moon next after the summer solstice, and lasted four years, which were of unequal lengths, because the time of full moon differs 11 days every year; so that they might sometimes begin on the next day after the solstice, and at other times not till four weeks after it. The first Olympiad began in the year of the Julian period 3938, which was 776 years before the first year of Christ, or 775 before the year of his birth; and the last Olympiad, which was the 293d, began A. D. 393. At the expiration of each Olympiad, the Olympic games were celebrated in the Elean fields, near the river Alpheus in the Peloponnesus (now Morea) in honour of Jupiter Olympus. See Strauchius's Breviarium Chronologicum, pp. 247–251.

[8] The reader may probably find it difficult to understand why Mr. Smith should reckon this eclipse to have been in the fourth year of the 48th Olympiad, as it was only in the end of the third year; and also why the 28th of May, in the 585th year before Christ, should answer to the present 10th of that month. But we hope the following explanation will remove these difficulties.

The month of May (when the Sun was eclipsed) in the 585th year before the first year of Christ, which was a leap year, fell in the latter end of the third year of the 48th Olympiad; and the fourth year of that Olympiad began at the summer solstice following: but perhaps Mr. Smith begins the years of the Olympiad from January, in order to make them correspond more readily with Julian years; and so reckons the month of May, when the eclipse happened, to be in the fourth year of that Olympiad.

The place or longitude of the Sun at that time was ♉ 29° 43′ 17″, to which same place the Sun returned (after 2300 years, viz.) A. D. 1716, on May 9^d 5^h 6^m after noon; so that, with respect to the Sun's place, the 9th of May 1716 answers to the 28th of May in the 585th year before the first year of Christ; that is, the Sun had the same longitude on both those days.

Thucydides's eclipse. 324. 'For a further illustration, Thucydides relates, that a solar eclipse happened on a summer's day in the afternoon, in the first year of the Peloponnesian war, so great that the stars appeared. Rhodius was victor in the Olympic games the 4th year of the said war, being also the 4th of the 87th Olympiad, or the 428th year before Christ. So that the eclipse must have happened in the 431st year before Christ; and by computation it appears, that on the 3d of August there was a signal eclipse which would have passed over Athens, central about 6 in the evening, but which our present tables bring no farther than the ancient Syrtes on the African coast, above 400 miles from Athens; which suffering in that case but 9 digits, could by no means exhibit the remarkable darkness recited by this historian; the centre, therefore, seems to have passed Athens about 6 in the evening, and probably might go down about Jerusalem, or near it, contrary to the construction of the present tables. I have only obviated these things by way of caution to the present astronomers, in recomputing ancient eclipses; and refer them to examine the eclipse of Nicias, so fatal to the Athenian fleet;[9] that which overthrew the Macedonian army,'[1] &c. So far Mr. Smith.

The number of eclipses. 325. In any year, the number of eclipses of both luminaries cannot be less than two, nor more than seven; the most usual number is four, and it is very rare to have more than six. For the Sun passes by both the nodes but once a-year, unless he passes by one of them in the beginning of the year; and if he does, he will pass by the same node again a little before the year be finished; because, as these points move $19\frac{1}{3}°$ backward every year, the Sun will come to either of them 173 days after the other, § 319. And when either node is within 17 degrees of the Sun at the time of new moon, the Sun will be eclipsed. At the subsequent opposition, the Moon will be eclipsed in the other node; and come round to the next conjunction again ere the former node be 17° past the Sun, and will therefore eclipse him again. When three eclipses fall about either node, the like number generally falls about the opposite; as the Sun comes to it in 173 days afterwards; and six lunations contain but four days more. Thus there may be two eclipses of the Sun, and one of the Moon, about

[9] Before Christ 413, August 27.

[1] Before Christ 168, June 21.

each of her nodes. But when the Moon changes in either of the nodes, she cannot be near enough the other node at the next full to be eclipsed; and in six lunar months afterward she will change near the other node: in these cases there can be but two eclipses in a year, and they are both of the Sun.

326. A longer period than the above-mentioned, § 320, for comparing and examining eclipses which happened at long intervals of time, is 557 years 21 days 18 hours 30 minutes 11 seconds, in which time there are 6890 mean lunations; and the Sun and node meet again so nearly as to be but 11 seconds distant;[2] but then it is not the same eclipse that returns, as in the shorter period above mentioned.

327. We shall subjoin a catalogue of eclipses recorded in history, from 721 years before Christ to A. D. 1485; of computed eclipses from 1485 to 1700; and of all the eclipses visible in Europe from 1700 to 1800. From the beginning of the catalogue to A. D. 1485, the eclipses are taken from Struyk's Introduction to Universal Geography, as that indefatigable author has, with much labour, collected them from Ptolemy, Thucydides, Plutarch, Calvisius, Xenophon, Diodorus Siculus, Justin, Polybius, Titus Livius, Cicero, Lucanus, Theophanes, Dion Cassius, and many others. From 1485 to 1700 the eclipses are taken from Ricciolus's Almagest: and from 1700 to 1800 from L'Art de vérifier les Dates. Those from Struyk have all the places mentioned where they were observed: those from the French authors, viz. the religious Benedictines of the congregation of St. Maur, are fitted to the meridian of Paris: and concerning those from Ricciolus, that author gives the following account:—

An account of the following catalogue of eclipses.

'Because it is of great use for fixing the cycles or revolutions of eclipses, to have at hand, without the trouble of calculation, a list of successive eclipses for many years, computed by authors of Ephemerides, although from tables not perfect in all respects, I shall, for the benefit of astronomers, give a summary collection of such. The authors I extract from are, an anonymous one who published Ephemerides from 1484 to 1506 inclusive: Jacobus Ptlaumen and Jo. Stæflerinus, to the meridian of Ulm, from 1507 to 1534: Lucas Gauricus, to the latitude of 45°,

[2] According to the latest solar and lunar tables, this period is only 557 years 21 days 18 hours 4 minutes 47 seconds, and the Sun's distance from the Moon's node is fully 1′ 41″. See *Ferguson's Lectures*, vol. ii, p. 83, edit. 2d.—*Edr*

from 1534 to 1551: Peter Appian, to the meridian of Leysing, from 1538 to 1578: Jo. Stœflerus, to the meridian of Tubing, from 1543 to 1554: Petrus Pitatus, to the meridian of Venice, from 1544 to 1556: Georgius-Joachimus Rheticus, for the year 1551: Nicholaus Simus, to the meridian of Bologna, from 1552 to 1568: Michael Mæstlin, to the meridian of Tubing, from 1557 to 1590: Jo. Stadius, to the meridian of Antwerp, from 1554 to 1574: Jo. Antoninus Maginus, to the meridian of Venice, from 1581 to 1630: David Origan, to the meridian of Franckfort on the Oder, from 1595 to 1664: Andrew Argol, to the meridian of Rome, from 1630 to 1700: Franciscus Montebrunus, to the meridian of Bologna, from 1461 to 1660: among which Stadius, Mæstlin, and Maginus, used the Prutenic tables; Origin the Prutenic and Tychonic; Montebrunus the Lansbergian, as likewise those of Durat. Almost all the rest the Alphonsine.

'But that the places may readily be known for which these eclipses were computed, and from what tables, consult the following list, in which the years inclusive are set down.

'From 1485	to 1506	The place and author unknown.
1507	1553	Ulm in Suabia, from the Alphonsine.
1554	1576	Antwerp, from the Prutenic.
1577	1585	Tubing, from the Prutenic.
1586	1594	Venice, from the Prutenic.
1595	1600	Franckfort on the Oder, from the Prutenic.
1601	1640	Franckfort on the Oder, from the Tychonic.
1641	1660	Bologna, from the Lansbergian.
1661	1700	Rome, from the Tychonic.'

So far Ricciolus.

N. B. The eclipses marked with an asterisk are not in Ricciolus's catalogue, but are supplied from L'Art de vérifier les Dates.

From the beginning of the catalogue to A. D. 1700, the time is reckoned from the noon of the day mentioned, to the noon of the following day: but from 1700 to 1800, the time is set down according to our common way of reckoning. Those marked Pekin and Canton are eclipses from the Chinese chronology according to Struyk; and throughout the table this mark ☉ signifies Sun, and this ☽ Moon.

Struyk's Catalogue of Eclipses.

Before Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle. H.	Middle. M.	Digits eclipsed.
721	Babylon	☽	March	19	10	34	Total.
720	Babylon	☽	March	8	11	56	1 5
720	Babylon	☽	Sept.	1	10	18	5 4
621	Babylon	☽	April	21	18	22	2 36
523	Babylon	☽	July	16	12	47	7 24
502	Babylon	☽	Nov.	19	12	21	1 52
491	Babylon	☽	April	25	12	12	1 44
431	Athens	☉	Aug.	3	6	35	11 0
425	Athens	☽	Oct.	9	6	15	Total.
424	Athens	☉	March	20	20	17	9 0
413	Athens	☽	Aug.	27	10	15	Total.
406	Athens	☽	April	15	8	50	Total.
404	Athens	☉	Sept.	2	21	12	8 40
403	Pekin	☉	Aug.	28	5	53	10 40
394	Gnide	☉	Aug.	13	22	17	11 0
383	Athens	☽	Dec.	22	19	6	2 1
382	Athens	☽	June	18	8	54	6 15
382	Athens	☽	Dec.	12	10	21	Total.
364	Thebes	☉	July	12	23	51	6 10
357	Syracuse	☉	Feb.	28	22	—	3 33
357	Zante	☽	Aug.	29	7	29	4 21
340	Zante	☉	Sept.	14	18	—	9 0
331	Arbela	☽	Sept.	20	10	9	Total.
310	Sicily Island	☉	Aug.	14	20	5	10 22
219	Mysia	☽	March	19	14	5	Total.
218	Pergamos	☽	Sept.	1	Rising.		Total.
217	Sardinia	☉	Feb.	11	1	57	9 6
203	Frusini	☉	May	6	2	52	5 40
202	Cumis	☉	Oct.	18	22	24	1 0
201	Athens	☽	Sept.	22	7	14	8 58
200	Athens	☽	March	19	13	9	Total.
200	Athens	☽	Sept.	11	14	48	Total.
198	Rome	☉	Aug.	6			
190	Rome	☉	March	13	18	—	11 0
188	Rome	☉	July	6	20	38	10 48
174	Athens	☽	April	30	14	33	7 1
168	Macedonia	☽	June	21	8	2	Total.
141	Rhodes	☽	Jan.	27	10	8	3 26
104	Rome	☉	July	18	22	0	11 52
63	Rome	☽	Oct.	27	6	22	Total.
60	Gibraltar	☉	March	16	Setting.		Central.
54	Canton	☉	May	9	3	41	Total.
51	Rome	☉	March	7	2	12	9 0
48	Rome	☽	Jan.	18	10	0	Total.
45	Rome	☽	Nov.	6	14	—	Total.
36	Rome	☉	May	19	3	52	6 47

Struyk's Catalogue of Eclipses.

Before Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle. H.	M.	Digits eclipsed.	
31	Rome	☉	Aug.	20	Setting.		Gr. Ecl.	
29	Canton	☉	Jan.	5	4	2	11	0
28	Pekin	☉	June	18	23	48	Total.	
26	Canton	☉	Oct.	23	4	16	11	15
24	Pekin	☉	April	7	4	11	2	0
16	Pekin	☉	Nov.	1	5	13	2	8
2	Canton	☉	Feb.	1	20	8	11	42
After Christ.								
1	Pekin	☉	June	10	1	10	11	43
5	Rome	☉	March	28	4	13	4	45
14	Panonia	☽	Sept.	26	17	15	Total.	
27	Canton	☉	July	22	8	56	Total.	
30	Canton	☉	Nov.	13	19	20	10	30
40	Pekin	☉	April	30	5	50	7	34
45	Rome	☉	July	31	22	1	5	17
46	Pekin	☉	July	21	22	25	2	10
46	Rome	☽	Dec.	31	9	52	Total.	
49	Pekin	☉	May	20	7	16	10	8
53	Canton	☉	March	8	20	42	11	6
55	Pekin	☉	July	12	21	50	6	40
56	Canton	☉	Dec.	25	0	28	9	20
59	Rome	☉	April	30	3	8	10	38
60	Canton	☉	Oct.	13	3	31	10	30
65	Canton	☉	Dec.	15	21	50	10	23
69	Rome	☽	Oct.	18	10	43	10	40
70	Canton	☉	Sept.	22	21	13	8	26
71	Rome	☽	March	4	8	32	6	0
95	Ephesus	☉	May	21			1	0
125	Alexandria	☽	April	5	9	16	1	44
133	Alexandria	☽	May	6	11	44	Total.	
134	Alexandria	☽	Oct.	20	11	5	10	19
136	Alexandria	☽	March	5	15	56	5	17
237	Bologna	☉	April	12			Total.	
238	Rome	☉	April	1	20	20	8	45
290	Carthage	☉	May	15	3	20	11	20
304	Rome	☽	Aug.	31	9	36	Total.	
316	Constantinople	☉	Dec.	30	19	53	2	18
334	Toledo	☉	July	17	At noon.		Central.	
348	Constantinople	☉	Oct.	8	19	24	8	0
360	Ispahan	☉	Aug.	27	18	0	Central.	
364	Alexandria	☽	Nov.	25	15	24	Total.	
401	Rome	☽	June	11			Total.	
401	Rome	☽	Dec.	6	12	15	Total.	
402	Rome	☽	June	1	8	43	10	2

Struyk's Catalogue of Eclipses.

After Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle. H.	M.	Digits eclipsed.	
402	Rome	☉	Nov.	10	20	33	10	30
447	Compostello	☉	Dec.	23	0	46	1	—
451	Compostello	☽	April	1	16	34	19	52
451	Compostello	☽	Sept.	26	6	30	0	2
458	Chaves	☉	May	27	23	16	18	53
462	Compostello	☽	March	1	13	2	11	11
464	Chaves	☉	July	19	19	1	10	15
484	Constantinople	☉	Jan.	13	9	53	10	0
486	Constantinople	☉	May	19	1	10	5	15
497	Constantinople	☉	April	18	6	5	17	57
512	Constantinople	☉	June	28	23	8	1	50
538	England ..	☉	Feb.	14	19	—	8	23
540	London	C	June	19	20	15	8	—
577	Tours	☽	Dec.	10	17	28	6	46
581	Paris	☽	April	4	13	33	6	42
582	Paris	☽	Sept.	17	12	41	Total.	
590	Paris	☽	Oct.	18	6	30	9	25
592	Constantinople	☉	March	18	22	6	10	0
603	Paris	☉	Aug.	12	3	3	11	20
622	Constantinople	☽	Feb.	1	11	28	Total.	
644	Paris	☉	Nov.	5	0	30	9	53
680	Paris	☽	June	17	12	30	Total.	
683	Paris	☽	April	16	11	30	Total.	
693	Constantinople	☉	Oct.	4	23	54	11	54
716	Constantinople	☽	Jan.	13	7	—	Total.	
718	Constantinople	☉	June	3	1	15	Total.	
733	England	☉	Aug.	13	20	—	11	1
734	England	☽	Jan.	23	14	—	Total.	
752	England	☽	July	30	13	—	Total.	
753	England	☉	June	8	22	—	10	35
753	England	☽	Jan.	23	13	—	Total.	
760	England	☉	Aug.	15	4	—	8	15
760	London	☽	Aug.	30	5	50	10	40
764	England	☉	June	4	At noon.		7	15
770	London	☽	Feb.	14	7	12	Total.	
774	Rome	☽	Nov.	22	14	37	11	58
784	London	☽	Nov.	1	14	2	Total.	
787	Constantinople	☉	Sept.	14	20	43	9	47
796	Constantinople	☽	March	27	16	22	Total.	
800	Rome	☽	Jan.	15	9	0	10	17
807	Angoulesme	☉	Feb.	10	21	24	9	42
807	Paris	☽	Feb.	25	13	43	Total.	
807	Paris	☽	Aug.	21	10	20	Total.	
809	Paris	☉	July	15	21	33	8	8
809	Paris	☽	Dec.	25	8	—	Total.	
810	Paris	☽	June	20	8	—	Total.	

Struyk's Catalogue of Eclipses.

After Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle. H.	Middle. M.	Digits eclipsed.
810	Paris	☉	Nov.	30	0	12	Total.
810	Paris	☽	Dec.	14	8	—	Total.
812	Constantinople	☉	May.	14	2	13	9 —
813	Cappadocia	☉	May	3	17	5	0 35
817	Paris	☽	Feb.	5	5	42	Total.
818	Paris	☉	July	6	18	—	6 35
820	Paris	☽	Nov.	23	6	26	Total.
824	Paris	☽	March	18	7	55	Total.
828	Paris	☽	June	30	15	—	Total.
828	Paris	☽	Dec.	24	13	45	Total.
831	Paris	☽	April	30	6	10	11 8
831	Paris	☉	May	15	23	—	4 24
831	Paris	☽	Oct.	24	11	15	Total.
832	Paris	☽	April	18	9	0	Total.
840	Paris	☉	May	4	23	22	9 20
841	Paris	☉	Oct.	17	18	58	5 24
842	Paris	☽	March	29	14	38	Total.
843	Paris	☽	March	19	7	1	Total.
861	Paris	☽	March	29	15	7	Total.
878	Paris	☽	Oct.	14	16	—	Total.
878	Paris	☉	Oct.	29	1	—	11 14
883	Arracta	☽	July	23	7	14	11 —
889	Constantinople	☉	April	3	17	52	9 23
891	Constantinople	☉	Aug.	7	23	18	10 30
901	Arracta	☽	Aug.	2	15	7	Total.
904	London	☽	May	31	11	47	Total.
904	London	☽	Nov.	25	9	0	Total.
912	London	☽	Jan.	6	15	12	Total.
926	Paris	☽	March	31	15	17	Total.
934	Paris	☉	April	16	4	30	11 36
939	Paris	☉	July	18	19	45	10 7
955	Paris	☽	Sept.	4	11	18	Total.
961	Rheims	☉	May	16	20	13	9 18
970	Constantinople	☉	May	7	18	38	11 22
976	London	☽	July	13	15	7	Total.
985	Messina	☉	July	20	3	52	4 10
989	Constantinople	☉	May	28	6	54	8 40
990	Fulda	☽	April	12	10	22	9 5
990	Fulda	☽	Oct.	6	15	4	1 10
990	Constantinople	☉	Oct.	21	0	45	10 5
995	Augsburg	☽	July	14	11	27	Total.
1009	Ferrara	☽	Oct.	6	11	38	Total.
1010	Messina	☽	March	18	5	41	9 12
1016	Nimeguen	☉	Nov.	16	16	39	Total.
1017	Nimeguen	☉	Oct.	22	2	8	6 —
1020	Cologne	☽	Sept.	4	11	38	Total.

Struyk's Catalogue of Eclipses.

After Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle. H.	Middle. M.	Digits eclipsed.
1023	London	☉	Jan.	23	23	29	11 —
1030	Rome	☽	Feb.	20	11	43	Total.
1031	Paris	☽	Feb.	9	11	51	Total.
1033	Paris	☽	Dec.	8	11	11	9 17
1034	Milan	☽	June	4	9	8	Total.
1037	Paris	☉	April	17	20	45	10 45
1039	Auxerre	☉	Aug.	21	23	40	11 5
1042	Rome	☽	Jan.	8	16	39	Total.
1044	Auxerre	☽	Nov.	7	16	12	10 1
1044	Cluny	☉	Nov.	21	22	12	11 —
1056	Nuremburg	☽	April	2	12	9	Total.
1063	Rome	☽	Nov.	8	12	16	Total.
1074	Augsburg	☽	Oct.	7	10	13	Total.
1080	Constantinople	☽	Nov.	29	11	12	9 36
1082	London	☽	May	14	10	32	10 2
1086	Constantinople	☉	Feb.	16	4	7	Total.
1089	Naples	☽	June	25	6	6	Total.
1093	Augsburg	☉	Sept.	22	22	35	10 12
1096	Gemblours	☽	Feb.	10	16	4	Total.
1096	Augsburg	☽	Aug.	6	8	21	Total.
1098	Augsburg	☉	Dec.	25	1	25	10 12
1099	Naples	☽	Nov.	30	4	58	Total.
1103	Rome	☽	Sept.	17	10	18	Total.
1106	Erfurt	☽	July	17	11	28	11 54
1107	Naples	☽	Jan.	10	13	16	Total.
1109	Erfurt	☉	May	31	1	30	10 20
1110	London	☽	May	5	10	51	Total.
1113	Jerusalem	☉	March	18	19	0	9 12
1114	London	☽	Aug.	17	15	5	Total.
1117	Triers	☽	June	15	13	26	Total.
1117	Triers	☽	Dec.	10	12	51	Total.
1118	Naples	☽	Nov.	29	15	46	4 11
1121	Triers	☽	Sept.	27	16	47	Total.
1122	Prague	☽	March	24	11	20	3 49
1124	Erfurt	☽	Feb.	1	6	43	8 39
1124	London	☉	Aug.	10	23	29	9 58
1132	Erfurt	☽	March	3	8	14	Total.
1133	Prague	☽	Feb.	20	16	41	3 23
1135	London	☽	Dec.	22	20	11	Total.
1142	Rome	☽	Feb.	11	14	17	8 30
1143	Rome	☽	Feb.	1	6	36	Total.
1147	Avranches	☉	Oct.	25	22	38	7 20
1149	Bary	☽	March	25	13	54	5 29
1151	Eimbeck	☽	Aug.	28	12	4	4 29
1153	Augsburg	☉	Jan.	26	0	42	11 —
1154	Paris	☽	June	26	16	1	Total.

Struyk's Catalogue of Eclipses.

After Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle. H.	M.	Digits eclipsed.	
1154	Paris	☽	Dec.	21	8	30	4	22
1556	Avranches	☽	June	16	8	45	0	53
1160	Rome	☽	Aug.	18	7	53	6	49
1161	Rome	☽	Aug.	7	8	15	Total.	
1162	Erfurt	☽	Feb.	1	6	40	5	56
1162	Erfurt	☽	July	27	12	30	4	11
1163	Mount Cassin	☉	July	3	7	40	2	0
1164	Milan	☽	June	6	10	0	Total.	
1168	London	☽	Sept.	18	14	0	Total.	
1172	Cologne	☽	Jan.	11	13	31	Total.	
1176	Avranches	☽	April	25	7	2	8	6
1176	Avranches	☽	Oct.	19.	11	20	8	53
1178	Cologne	☽	March	5	Setting.		7	52
1178	Avranches	☽	Aug.	29	13	52	5	31
1178	Cologne	☉	Sept.	12			10	51
1179	Cologne	☽	Aug.	18	14	28	Total.	
1180	Avranches	☉	Jan.	28	4	14	10	34
1181	Avranches	☉	July	13	3	15	3	48
1181	Avranches	☽	Dec.	22	8	58	4	40
1185	Rheims	☉	May	1	1	53	9	0
1186	Cologne	☽	April	5	6	—	Total.	
1186	Franckfort	☉	April	20	7	19	4	0
1187	Paris	☽	March	25	16	17	8	42
1187	England	☉	Sept.	3	21	54	8	6
1189	England	☽	Feb.	2	10	—	9	—
1191	England	☉	June	23	0	20	11	32
1192	France	☽	Nov.	20	14	—	6	—
1193	France	☽	Nov.	10	5	27	Total.	
1194	London	☉	April	22	2	16	6	49
1200	London	☽	Jan.	2	17	2	4	35
1201	London	☽	June	17	15	4	Total.	
1204	England	☽	April	15	12	39	Total.	
1204	Salzburg	☽	Oct.	10	6	32	Total.	
1207	Rheims	☉	Feb.	27	10	50	10	20
1208	Rheims	☽	Feb.	2	5	10	Total.	
1211	Vienna	☽	Nov.	21	18	57	Total.	
1215	Cologne	☽	March	16	15	35	Total.	
1216	Acre	☉	Feb.	18	21	15	11	36
1216	Acre	☽	March	5	9	38	7	4
1218	Damietta	☽	July	9	9	46	11	31
1222	Rome	☽	Oct.	22	14	28	Total.	
1223	Colmar	☽	April	16	8	13	11	0
1228	Naples	☉	Dec.	27	9	55	9	19
1230	Naples	☉	May	13	17	—	Total.	
1230	London	☽	Nov.	21	13	21	9	34
1232	Rheims	☉	Oct.	15	4	29	4	25

Struyk's Catalogue of Eclipses.

After Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle H.	M.	Digits eclipsed.	
1245	Rheims	☉	July	24	17	47	6	—
1248	London	☽	June	7	8	49	Total.	
1255	London	☽	July	20	9	47	Total.	
1255	Constantinople	☉	Dec.	30	2	52	Annul.	
1258	Augsburg	☽	May	18	11	17	Total.	
1261	Vienna	☉	March	31	22	40	9	8
1262	Vienna	☽	March	7	5	50	Total.	
1262	Vienna	☽	Aug.	30	14	39	Total.	
1263	Vienna	☽	Feb.	24	6	52	6	29
1263	Augsburg	☉	Aug.	5	3	24	11	17
1263	Vienna	☽	Aug.	20	7	35	9	7
1265	Vienna	☽	Dec.	23	16	25	Total.	
1267	Constantinople	☉	May	24	23	11	11	40
1270	Vienna	☉	March	22	18	47	10	40
1272	Vienna	☽	Aug.	10	7	27	8	53
1274	Vienna	☽	Jan.	23	10	39	9	25
1275	Lauben	☽	Dec.	4	6	20	4	29
1276	Vienna	☽	Nov.	22	15	—	Total.	
1277	Vienna	☽	May	18			Total.	
1279	Franckfort	☉	April	12	6	55	10	6
1280	London	☽	March	17	12	12	Total.	
1284	Reggio	☽	Dec.	23	16	11	9	13
1290	Wittemburg	☉	Sept.	5	19	37	10	30
1291	London	☽	Feb.	14	10	2	Total.	
1302	Constantinople	☽	Jan.	14	10	25	Total.	
1307	Ferrara	☉	April	2	22	18	0	54
1309	London	☽	Feb.	24	17	44	Total.	
1309	Lucca	☽	Aug.	21	10	32	Total.	
1310	Wittemburg	☉	Jan.	31	2	2	10	10
1310	Torcello	☽	Feb.	14	4	8	10	20
1310	Torcello	☽	Aug	10	15	33	7	16
1312	Wittemburg	☉	July	4	19	49	3	23
1312	Plaisance	☽	Dec.	14	7	19	Total.	
1313	Torcello	☽	Dec.	3	8	58	9	34
1316	Modena	☽	Oct.	1	14	55	Total.	
1321	Wittemburg	☉	June	25	18	1	11	17
1323	Florence	☽	May	20	15	24	Total.	
1324	Florence	☽	May	9	6	3	Total.	
1324	Wittemburg	☉	April	23	6	35	8	8
1327	Constantinople	☽	Aug.	31	18	26	Total.	
1328	Constantinople	☽	Feb.	25	13	47	11	—
1330	Florence	☽	June	30	15	10	7	34
1330	Constantinople	☉	July	16	4	5	10	43
1330	Prague	☽	Dec.	25	15	49	Total.	
1331	Prague	☉	Nov.	29	20	26	7	41
1331	Prague	☽	Dec.	14	18	—	11	—

Struyk's Catalogue of Eclipses.

After Christ.	Eclipses of the Sun and Moon seen at		M.	D.	Middle. H.	M.	Digits Eclipsed.	
1333	Wittemburg	☉	May	14	3	—	10	18
1334	Cesena	☽	April	19	10	33	Total.	
1341	Constantinople	☽	Nov.	28	12	23	Total.	
1341	Constantinople	☉	Dec.	8	22	15	6	30
1342	Constantinople	☽	May	20	14	27	Total.	
1344	Alexandria	☉	Oct.	6	18	40	8	57
1349	Wittemburg	☽	June	30	12	20	Total.	
1354	Wittemburg	☉	Sept.	16	20	45	8	43
1356	Florence	☽	Feb.	16	11	43	Total.	
1361	Constantinople	☉	May	4	22	15	8	54
1367	Sienna	☽	Jan.	16	8	27	Total.	
1389	Eugibio	☽	Nov.	3	17	5	Total.	
1396	Augsburg	☉	Jan.	11	0	16	6	22
1396	Augsburg	☽	June	21	11	10	Total.	
1399	Forli	☉	Oct.	29	0	43	9	—
1406	Constantinople	☽	June	1	13	—	10	31
1406	Constantinople	☉	June	15	18	1	11	38
1408	Forli	☉	Oct.	18	21	47	9	32
1409	Constantinople	☉	April	15	3	1	10	48
1410	Vienna	☽	March	20	13	13	Total.	
1415	Wittemburg	☉	June	6	6	47	Total.	
1419	Franckfort	☉	March	25	22	5	1	17
1421	Forli	☽	Feb.	17	8	2	Total.	
1422	Forli	☽	Feb.	6	8	26	11	7
1424	Wittemburg	☉	June	26	3	57	11	20
1431	Forli	☉	Feb.	12	2	4	1	59
1433	Wittemburg	☉	June	17	5	—	Total.	
1438	Wittemburg	☉	Sept.	18	20	59	8	7
1442	Rome	☽	Dec.	17	3	56	Total.	
1448	Tubing	☉	Aug.	28	22	23	8	53
1450	Constantinople	☽	July	24	7	19	Total.	
1457	Vienna	☽	Sept.	3	11	17	Total.	
1460	Austria	☽	July	3	7	31	5	23
1460	Austria	☉	July	17	17	32	11	19
1460	Vienna	☽	Dec.	27	13	30	Total.	
1461	Vienna	☽	June	22	11	50	Total.	
1461	Rome	☽	Dec.	17			Total.	
1462	Viterbo	☽	June	11	15	—	7	38
1462	Viterbo	☉	Nov.	21	0	10	2	6
1464	Padua	☽	April	21	12	43	Total.	
1465	Rome	☉	Sept.	20	5	15	8	46
1465	Rome	☽	Oct.	4	5	12	Total.	
1469	Rome	☽	Jan.	27	7	9	Total.	
1485	Nuremburg	☉	March	16	3	53	11	—

All the following Eclipses are taken from Ricciolus, except those ed with an Asterisk, which are from L'Art de vérifier les Dates.

After Christ.		M.	D.	Middle. H.	M.	Digits eclipsed.
1486	☽	February	18	5	41	Total.
1486	• ☉	March	5	17	43	9 0
1487	☽	February	7	15	49	Total.
1487	☉	July	20	2	6	7 0
1488	☽	January	28	6	—	*
1488	☉	July	8	17	30	4 0
1489	☽	·· December	7	17	41	Total.
1490	☉	May	19	Noon.		*
1490	☽	June	2	10	6	Total.
1490	☽	November	26	18	25	Total.
1491	☉	March	8	2	19	9
1491	☽	November	15	18	—	*
1492	☉	April	26	7	—	*
1492	☉	October	20	23	—	*
1493	☽	April	1	14	0	Total.
1493	☉	October	10	2	40	8 0
1494	☉	March	7	4	12	4 0
1494	☽	March	21	14	38	Total.
1494	☽	September	14	19	45	Total.
1495	☽	March	10	16	—	*
1495	☉	August	19	17	—	*
1496	☽	January	29	14	—	*
1497	☽	January	18	6	38	Total.
1497	☉	July	29	3	2	3 0
1499	☽	June	22	17	—	*
1499	☉	August	23	18	—	*
1499	☽	November	17	10	—	*
1500	☉	March	27	In the		Night.
1500	☽	April	11		At	Noon.
1500	☽	October	5	14	2	10 0
1501	☽	May	2	17	49	Total.
1502	☉	September	30	19	45	10 0
1502	☽	October	15	12	20	2 0
1503	☽	March	12	9	—	*
1503	☉	September	19	22	—	*
1504	☽	February	29	13	36	Total.
1504	☉	March	16	3	—	*
1505	☽	August	14	8	18	Total.
1506	☽	February	7	15	—	*
1507	☉	July	20	3	11	*2 0

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H.	M.	Digits eclipsed.
1506	☽	August	3	10	—	*
1507	☉	January	12	19	—	*
1508	☉	January	2	4	—	*
1508	☉	May	29	6	—	*
1508	☽	June	12	17	40	Total.
1509	☽	June	2	11	11	7 0
1509	☉	November	11	22	—	*
1510	☽	October	16	19	—	*
1511	☽	October	6	11	50	Total
1512	☽	September	25	3	56	Total.
1513	☉	March	7	0	30	6
1513	☉	July	30	1	—	*
1515	☽	January	29	15	18	Total.
1516	☽	January	19	6	0	Total.
1516	☽	July	13	11	37	Total.
1516	☉	December	23	3	47	3 0
1517	☉	June	18	16	—	*
1517	☽	November	27	19	—	*
1518	☽	May	24	11	19	9 11
1518	☉	June	7	17	56	11 0
1519	☉	May	28	1	—	*
1519	☉	October	28	4	33	6 0
1519	☽	November	6	6	24	Total.
1520	☽	May	2	7	—	*
1520	☉	October	11	5	22	3
1520	☽	October	25	19	—	*
1520	☽	March	21	17	—	*
1521	☽	April	6	19	—	*
1521	☉	September	30	3	—	*
1522	☽	September	5	12	17	Total.
1523	☽	March	1	8	26	Total.
1523	☽	August	25	15	24	Total.
1524	☉	February	4	1	—	*
1524	☽	August	16	16	—	*
1525	☉	January	23	4	—	*
1525	☽	July	4	10	10	Total.
1525	☽	December	29	10	46	Total.
1526	☽	December	18	10	30	Total.
1527	☉	January	2	3	—	*
1527	☽	December	7	10	—	*
1528	☉	May	17	20	—	*
1529	☽	October	16	20	23	11 55
1530	☉	March	28	18	23	8 24
1530	☽	October	6	12	11	Total.
1531	☽	April	1	7	—	*
1532	☉	August	30	0	49	3 3

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle H.	Middle M.	Digits Eclipsed.
1533	☽	August	4	11	50	Total.
1533	○	August	19	17	—	*
1534	☉	January	14	1	42	5 45
1534	☽	January	29	14	25	Total.
1535	○	June	30	Noon.		*
1535	☽	July	14	8	—	*
1535	○	December	24	2	—	*
1536	☉	June	18	2	2	8 0
1536	☽	November	27	6	21	10 15
1537	☽	May	24	8	3	Total.
1537	○	June	7	8	—	*
1537	☽	November	16	14	56	Total.
1538	☽	May	13	14	24	3 0
1538	☽	November	6	5	31	3 37
1539	☉	April	8	4	33	9 0
1540	○	April	6	17	15	Total.
1541	☽	March	11	16	34	Total.
1541	○	August	21	0	56	3 0
1542	☽	March	1	8	46	1 38
1542	○	August	10	17	—	*
1543	☽	July	15	16	—	*
1544	☽	January	9	18	13	Total.
1544	☉	January	23	21	16	11 17
1544	☽	July	4	8	31	Total.
1544	☽	December	28	18	27	Total.
1545	○	June	8	20	48	3 45
1545	☽	December	17	18	—	*
1546	☉	May	30	5	—	*
1546	○	November	22	23	—	*
1547	☽	May	4	10	27	8 0
1547	☽	October	28	4	56	11 34
1547	Ↄ	November	12	2	9	9 30
1548	☉	April	8	3	—	*
1548	☽	April	22	11	24	Total.
1549	☽	April	11	15	19	2 0
1549	☽	October	6	6	—	*
1550	☉	March	16	20	—	*
1551	☽	February	20	8	21	Total.
1551	○	August	31	2	0	1 52
1553	☉	January	12	22	54	1 22
1553	☉	July	10	7	—	*
1553	☽	July	24	16	0	0 31
1554	☉	June	29	6	—	*
1554	☽	December	8	13	7	10 12
1555	☽	June	4	15	0	Total.
1555	○	November	13	19	—	*

Ricciolus's Catalogue of Eclipses.

After Christ.		M	D	Middle H	M	Digits Eclipsed
1556	☉	November	1	18	0	9 41
1556	☽	November	16	12	44	6 55
1557		October	20	20	—	*
1558	☽	April	2	11	0	9 50
1558		April	18	1	—	*
1559	☽	April	16	4	0	Total
1560	☽	March	11	15	10	4 13
1560		August	21	1	—	6 22
1560	☽	September	5	7	—	*
1561		February	13	19	—	*
1562		February	3	5	—	*
1562	☽	July	15	15	50	Total
1563		January	22	19	—	*
1563		June	20	4	55	8 58
1563	☽	July	5	8	4	11 54
1565	☾	March	7	12	53	——
1565	☽	May	14	16	—	*
1565	☽	November	7	12	16	11 46
1566	☽	October	28	5	38	Total
1567	☾	April	8	23	4	6 34
1567	☽	October	17	15	45	2 40
1568	☉	March	28	5	—	*
1569	☽	March	2	15	18	Total
1570	☽	February	20	5	46	Total
1570	☽	August	15	9	17	Total
1571	☾	January	25	4	—	*
1572	☾	January	14	19	—	*
1572	☽	June	25	9	0	5 26
1573		June	28	18	—	*
1573		November	21	4	—	* *
1573	☽	December	8	6	51	Total
1574		November	13	3	50	5 21
1575		May	19	8	—	6 0
1575		November	2	5	—	*
1576	☽	October	7	9	15	——
1577	☽	April	2	8	55	Total
1577	☽	September	26	13	4	Total
1578	☽	September	15	13	4	2 20
1579		February	15	5	41	8 36
1579	☉	August	20	19	0	*
1580	☽	January	31	10	7	Total.
1581	☽	January	19	9	22	Total
1581	☽	July	15	17	51	Total
1582	☽	January	8	10	29	0 53
1582	☉	June	9	17	5	7 5
1583	☽	November	28	21	51	Total

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H. M.	Digits eclipsed.
1584	☉	May	9	18 20	3 36
1584	☽	November	17	14 15	Total.
1585	☉	April	29	7 53	11 7
1585	☽	May	13	5 9	6 54
1586	☽	September	27	8 —	*
1586	☉	October	12	Noon.	*
1587	☽	September	16	9 28	10 2
1588	☉	February	26	1 23	1 3
1588	☽	March	12	14 14	Total.
1588	☽	September	4	17 30	Total.
1589	☉	August	10	18 —	*
1589	☽	August	25	8 1	3 45
1590	☉	February	4	5 —	*
1590	☽	July	16	17 4	3 54
1590	☉	July	30	19 57	10 27
1591	☽	January	9	6 21	9 40
1591	☽	July	6	5 8	Total.
1591	☉	July	20	4 2	1 0
1591	☽	December	29	16 11	Total.
1592	☽	June	24	10 13	8 58
1592	☽	December	18	7 24	5 54
1593	☉	May	30	2 30	2 38
1594	☉	May	19	14 58	10 23
1594	☽	October	28	19 15	9 40
1595	☉	April	9	Ter. del	Feugo.
1595	☽	April	24	4 12	Total.
1595	☉	May	7	22 —	*
1595	☉	October	3	2 4	5 18
1595	☽	October	18	20 47	Total.
1596	☉	March	28	In	Chili.
1596	☽	April	12	8 52	6 4
1596	☉	September	21	In	China.
1596	☽	October	6	21 15	3 33
1597	☉	March	16	St. Pet.	Isle.
1597	☉	September	11	Picora.	9 49
1598	☽	February	20	18 12	10 55
1598	☉	March	6	22 12	11 57
1598	☽	August	16	1 15	Total.
1598	☉	August	31	Magel.	8 34
1599	☽	February	10	18 21	Total.
1599	☉	July	22	4 31	8 18
1599	☽	August	6	———	Total.
1600	☉	January	15	Java.	11 48
1600	☽	January	30	6 40	2 58
1600	☉	July	10	2 10	5 39
1601	☉	January	4	Ethiop.	9 40

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H. M.	Digits Eclipsed.
1601	☽	June	15	6 18	4 52
1601	☉	June	29	China.	4 29
1601	☽	December	9	7 6	10 53
1601	☉	December	24	2 46	9 52
1602	☉	May	21	Greenl.	2 41
1602	☽	June	4	7 18	Total.
1602	☉	June	19	N. Gra.	5 43
1602	☉	November	13	Magel.	3 —
1602	☽	November	28	10 2	Total.
1603	☉	May	10	China.	11 21
1603	☽	May	24	11 41	7 59
1603	☉	November	3	Rom. l.	11 17
1603	☽	November	18	7 31	3 26
1604	☉	April	20	Arabia.	9 32
1604	☉	October	22	Peru.	6 49
1605	☽	April	3	9 19	11 49
1605	☉	April	18	Madag.	5 31
1605	☽	September	27	4 27	9 26
1605	☉	October	12	2 32	9 24
1606	☉	March	8	Mexico.	6 0
1606	☽	March	24	11 17	Total.
1606	☉	September	2	Magel.	6 40
1606	☉	September	2	Magel.	6 10
1606	☽	September	16	15 6	Total.
1607	☉	February	25	21 48	1 13
1607	☽	March	13	6 36	1 22
1607	☉	September	5	15 40	1 7
1608	☉	February	15	At the	Antipo.
1608	☽	July	27	0 30	1 53
1608	☉	August	9	4 39	0 40
1609	☽	January	19	15 21	10 32
1609	☉	February	4	Feugo.	5 22
1609	☉	July	16	12 8	Total.
1609	☽	July	30	Canada.	4 10
1609	☉	December	26	19 —	5 50
1610	☽	January	9	1 31	Total.
1610	☉	June	20	Java.	10 46
1610	☽	July	5	16 58	11 13
1610	☉	December	15	Cyprus.	4 50
1610	☽	December	29	16 47	4 23
1611	☉	June	10	Califor.	11 30
1611	☽	May	14	10 38	7 22
1612	☉	May	29	23 38	7 14
1612	☽	November	8	3 22	9 49
1612	☉	November	22	Magel.	9 0
1613	☉	April	20	Magel	lanica.

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H. M.	Digits eclipsed.
1613	☽	May	4	0 35	Total.
1613	☉	May	19	East	Tartary.
1613	☉	October	13	South	America.
1613	☽	October	28	4 19	Total.
1614	☉	April	8	N. Gui.	8 44
1614	☽	April	23	17 36	5 25
1614	☉	October	3	0 57	5 2
1614	☽	October	17	4 38	4 56
1615	☉	March	29	Goa.	10 34
1615	☉	September	22	Salom	Isle.
1615	☽	March	3	1 58	Total.
1616	☉	March	17	Mexico.	6 47
1616	☽	August	26	15 33	Total.
1616	☽	September	10	Magel.	10 33
1617	☉	February	5	Magel	lanica.
1617	☽	February	20	1 49	Total.
1617	☉	March	6	22 —	
1617	☉	August	1	Biarmia.	*
1617	☽	August	16	8 22	Total.
1618	☉	January	16	Magel	lanica.
1618	☽	February	9	3 29	2 57
1618	☉	July	21	Mexico.	———
1619	☉	January	15	Califor	nia
1619	☽	June	26	12 40	5 10
1619	☉	July	11	Africa.	11 39
1619	☉	December	20	15 58	10 47
1620	☽	May	31	Arctic	Circle.
1620	☽	June	14	13 47	Total.
1620	☉	June	29	Magel.	7 20
1620	☽	December	9	6 39	Total.
1620	☉	December	23	Magel	lanica.
1621	☉	May	20	14 54	10 44
1621	☽	June	3	19 42	9 53
1621	☉	November	13	Magel	lanica.
1621	☽	November	28	15 43	3 28
1622	☉	May	10	C. Verd.	11 52
1622	☉	November	2	Malacca	In.
1623	☽	April	14	7 19	10 54
1623	☉	April	29	———	———
1623	☽	October	8	0 22	8 35
1623	☉	October	23	Califor.	10 46
1624	☉	May	18	N. Zem.	6 0
1624	☽	April	3	7 9	Total.
1624	☉	April	17	Antar.	Circle.
1624	☉	September	12	Magel	lanica.
1624	☽	September	26	8 55	Total.

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle H. M.	Digits eclipsed.
1625	☉	March	8	Florida.	
1625	☽	March	23	14 11	2 11
1625	☉	September	1	St. Peter's	Isle.
1625	☽	September	16	11 41	5 6
1626	☉	February	25	Madag.	8 27
1626	☽	August	7	7 48	0 25
1626	☉	August	21	In	Mexico.
1627	☽	January	30	11 38	10 21
1627	☉	February	15	Magel	lanica.
1627	☽	July	27	9 4	Total.
1627	☉	August	11	Tenduc.	10 0
1628	☉	January	6	Tenduc.	5 40
1628	☽	January	20	10 11	Total.
1628	☉	July	1	C. Good	Hope.
1628	☽	July	16	11 26	Total.
1628	☉	December	25	In Eng	land.
1629	☽	January	9	1 36	4 27
1629	☉	June	11	Gange.	11 25
1629	☉	December	14	Peru.	10 14
1630	☽	May	25	17 56	6 0
1630	☉	June	10	7 47	9 8
1630	☽	November	19	11 24	9 27
1630	☉	December	3	N. Guin.	10 10
1631	☉	April	30	Antar.	Circle.
1631	☽	May	15	8 15	Total.
1631	☉	October	14	C. Good.	Hope.
1631	☽	November	8	12 0	Total.
1632	☉	April	19	C. Good.	Hope.
1632	☽	May	4	1 24	6 35
1632	☉	October	13	Mexico.	8 37
1632	☽	October	17	12 23	5 31
1633	☉	April	8	5 14	4 30
1633	☉	October	3	Maldiv.	Total.
1634	☽	March	14	9 35	11 18
1634	☉	March	28	Japan.	10 19
1634	☽	September	7	5 0	Total.
1634	☉	September	22	C. G. H.	9 54
1635	☉	February	17	Antar.	Circle.
1635	☽	March	3	9 26	Total.
1635	☉	March	18	Mexico.	0 16
1635	☉	August	12	Iceland.	5 0
1635	☽	August	27	16 4	Total.
1636	☉	February	6	In	Peru.
1636	☽	February	20	11 34	3 23
1636	☉	August	1	Tartary.	11 20
1636	☽	August	16	4 34	1 25

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H.	M.	Digits eclipsed.	
1637	☉	January	26		Cam	boya.	
1637	☉	July	21	Jucutan.			
1637	☽	December	31	0	44	10	45
1638	☉	January	14	Persia.		9	45
1638	☽	June	25	20	17	Total.	
1638	☉	July	11	Magel-		9	5
1638	☉	December	5	lan.		2	10
1638	☽	December	20	15	16	Total.	
1639	☉	January	4	Tartary.		0	30
1639	☉	June	1	5	29	10	40
1639	☽	June	15	2	41	11	9
1639	☉	November	24	Magel		11	0
1639	☽	December	9	11	57	3	46
1640	☉	May	20	N. Spa.		10	30
1640	☉	November	13	Peru.	2	10	36
1641	☽	April	25	1	0	9	49
1641	☉	May	9	Peru.		10	16
1641	☽	October	18	8	19	6	31
1641	☉	November	2	18	46	——	
1642	☉	March	30	Estotl.		4	0
1642	☽	April	14	14	31	Total.	
1642	☉	September	25		Magel	lanica.	
1642	☽	October	7	16	45	Total.	
1643	☉	March	19	13	53	——	
1643	☽	April	3	21	10	3	9
1643	☉	September	12	17	0	——	
1643	☽	September	27	7	38	6	0
1644	☉	March	8	6	20	——	
1644	☉	August	13	18	10	——	
1645	☽	February	10	7	45	8	52
1645	☉	February	26	Rom. I.		10	46
1645	☽	August	7	2	4	Total.	
1645	☉	August	21	0	35	4	40
1646	☉	January	16	Str. of		Anian.	
1646	☽	January	30	18	11	Total.	
1646	☉	July	12	6	57	——	
1646	☽	July	27	6	2	Total.	
1647	☉	January	5	12	10	——	
1647	☽	January	20	9	43	4	47
1647	☉	July	2	0	9	——	
1647	☉	December	25	13	38	——	
1648	☽	June	5	0	55	4	28
1648	☉	June	20	13	28	——	
1648	☽	November	29	19	17	7	40
1648	☉	December	13	21	48	——	
1649	☽	May	25	15	20	Total.	

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H.	M.	Digits eclipsed.	
1649	☉	June	9	Arct. C.		4	0
1649	☉	November	4	2	10	3	19
1649	☽	November	18	19	56	Total.	
1650	☉	April	30	5	54	——	
1650	☽	May	15	8	37	7	57
1650	☉	October	24	17	17	——	
1650	☽	November	7	20	29	5	3
1651	☉	April	19	Tub. r		——	
1651	☉	October	14	2	15	——	
1652	☽	March	24	16	52	8	50
1652	☉	April	7	22	40	9	59
1652	☽	September	17	7	27	9	49
1652	☉	October	2	5	2	——	
1653	☉	February	27	——		——	
1653	☽	March	13	17	9	Total.	
1653	☉	August	22	——		——	
1653	☽	September	6	23	45	Total	
1654	☉	February	16	9	10	——	
1654	☽	March	2	19	25	3	14
1654	☉	August	11	22	24	2	28
1654	☽	August	27	11	40	1	53
1655	☉	February	6	2	37	4	20
1655	☉	August	1	14	19	——	
1655	☽	August	16	16	—	*	
1656	☽	January	11	9	4	10	0
1656	☽	July	6	3	17	Total.	
1656	☉	July	21	11	48	——	
1656	☽	December	30	23	30	Total.	
1657	☉	June	11	11	20	——	
1657	☽	June	25	9	35	Total.	
1657	☉	December	4	20	0	——	
1657	☽	December	20	7	47	3	9
1658	☉	May	31	16	0	——	
1658	☽	June	14	22	58	——	
1658	☽	November	9	13	56	0	10
1658	☉	November	24	11	36	——	
1659	☽	May	6	8	34	8	5
1659	☉	May	20	17	4	——	
1659	☽	October	29	16	16	5	52
1659	☉	November	14	4	25	9	51
1660	☽	April	24	21	58	Total.	
1660	☉	October	3	22	34	——	
1660	☽	October	18	0	32	Total.	
1660	☉	November	2	13	48	——	
1661	☉	March	29	22	32	——	
1661	☽	April	11	84	28	——	

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H.	Middle. M.	Digits eclipsed.
1661	☉	September	23	1	36	11 19
1661	☽	October	7	14	51	7 4
1662	☉	March	19	15	8	—
1662	☉	April	12	1	8	—
1663	☽	February	21	16	11	3 14
1663	☉	March	9	5	47	—
1663	☽	August	18	8	45	Total.
1663	☉	September	1	8	8	—
1664	☉	January	27	20	40	—
1664	☽	February	11	3	16	—
1664	☉	July	22	14	48	—
1664	☉	August	20	22	10	—
1665	☽	January	30	18	47	3 34
1665	☉	July	12	7	48	—
1665	☽	July	26	13	31	0 10
1666	☉	January	4	21	33	—
1666	☉	July	1	19	0	11 10
1667	☽	June	5	Noon.		—
1667	☉	July	21	2	32	—
1667	☉	November	15	11	30	—
1668	☉	May	10	Setting.		—
1668	☽	May	25	16	26	9 32
1668	☉	November	4	2	53	9 50
1668	☽	November	18	3	54	6 45
1669	☉	April	29	18	18	—
1669	☉	October	24	10	13	—
1670	☉	April	19	7	0	—
1670	☉	September	10	19	0	—
1670	☽	September	28	15	43	9 7
1670	☉	October	13	12	5	—
1671	☉	April	8	23	29	—
1671	☉	September	18	21	25	—
1671	☽	September	18	7	44	Total.
1672	☉	February	28	3	38	—
1672	☽	March	13	3	17	—
1672	☉	August	44	6	43	—
1672	☽	September	6	18	54	—
1673	☉	February	16	7	29	—
1673	☉	August	22	21	44	—
1674	☽	January	21	18	22	11 21
1674	☉	February	5	9	4	—
1674	☽	July	17	9	40	Total.
1675	☽	January	11	8	29	Total.
1675	☉	January	25	10	36	—
1675	☽	July	6	16	31	Total.
1676	☉	June	10	21	26	4 34

Riccioli's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H.	M.	Digits eclipsed.
1676	☽	June.	25	6	26	——
1676	☉	December	4	20	52	——
1677	☉	November	24	12	5	——
1677	☽	May	16	16	25	8 15
1678	☽	May	6	5	30	——
1678	☽	October	29	9	17	Total.
1679	☉	April	10	21	0	——
1679	☽	May	25	11	53	5 47
1680	☉	March	19	23	22	——
1680	☉	September	22	7	57	——
1680	☽	March	4	Noon.		——
1681	☉	March	29	13	43	——
1681	☽	August	28	15	22	10 35
1681	☉	September	11	15	43	——
1682	☽	February	21	12	28	Total.
1682	☽	August	17	18	56	Total.
1683	☉	January	27	1	35	10 30
1683	☽	February	9	3	39	——
1683	☽	August	6	20	36	——
1684	☉	January	16	6	34	——
1684	☽	June	26	15	18	1 35
1684	☉	July	12	4	26	Total.
1684	☽	December	21	11	18	9 45
1685	☉	January	4	16	0	——
1685	☽	June	16	6	0	——
1685	☽	December	10	11	26	Total.
1686	☉	May	21	17	9	——
1686	☽	June	6	Noon.		——
1686	☽	November	29	12	22	Total.
1687	☉	May	11	1	—	*
1687	☽	May	26	14	—	*
1687	☽	April	15	7	4	6 49
1688	☉	April	29	16	27	——
1688	☽	October	9	Noon.		——
1688	☉	October	25	19	40	——
1689	☽	April	4	7	42	Total.
1689	☽	September	28	15	46	Total.
1690	☉	March	10	——		——
1690	☽	March	24	11	14	5 43
1690	☉	September	3	——		——
1690	☽	September	18	2	42	——
1691	☉	February	27	17	30	——
1691	☉	August	23	5	51	——
1692	☽	February	2	3	20	——
1692	☉	February	16	17	31	——
1692	☽	July	27	16	9	Total.

Ricciolus's Catalogue of Eclipses.

After Christ.		M.	D.	Middle. H.	M.	Digits eclipsed.	
1693	☽	January	21	17	25	Total.	
1693	☽	July	17	Noon.		———	
1694	☽	January	11	Noon.		———	
1694	☉	June	22	4	22	6	22
1694	☽	July	6	13	51	0	47
1695	☉	May	11	6	3	———	
1695	☽	May	28	Noon.		———	
1695	☽	November	20	8	0	6	55
1695	☉	December	5	17	7	———	
1696	☽	May	16	12	45	Total.	
1696	☉	May	30	12	56	———	
1696	☽	November	8	17	30	Total.	
1696	☉	November	23	17	32	———	
1697	☉	April	20	14	32	———	
1697	☽	May	5	18	27	———	
1697	☽	October	29	8	44	8	54
1698	☉	April	10	9	13	———	
1698	☉	October	3	15	29	———	
1699	☽	March	15	8	14	9	7
1699	☉	March	30	22	0	———	
1699	☽	September	8	23	22	———	
1699	☉	September	23	22	38	9	58
1700	☽	March	4	20	11	———	
1700	☽	August	29	1	42	———	

The Eclipses from Struyk were observed; those from Ricciolus calculated: the following from *L'Art de vérifier les Dates*, are only those which were visible in Europe last century: those which are total are marked with a *T*; and *M* signifies morning, and *A* afternoon.

Visible Eclipses from 1700 *to* 1800.

After Christ.		Months and days.	Time of the day or night.	After Christ.		Months and days	Time of the day or night
1701	☽	Feb. 22	11 A.	1729	☽	Aug. 9	1 M.
1703	☽	Jan. 8	7 M.	1730	☽	Feb. 4	4 M.
1703	☽	June 29	1 M. T.	1731	☽	June 20	2 M.
1703	☽	Dec. 23	7 M. T.	1732	☽	Dec. 1	10 A. T.
1704	☽	Dec. 11	7 M.	1733	☉	May 13	7 A.
1706	☽	April 28	2 M.	1733	☽	May 28	7 A.
1706	☉	May 12	10 M.	1735	☽	Oct. 2	1 M.
1706	☽	Oct. 21	7 A.	1736	☽	March 26	12 A. T.
1707	☽	April 17	2 M. T.	1736	☽	Sept. 20	3 M. T.
1708	☽	April 5	6 M.	1736	☉	Oct. 4	6 A.
1708	☉	Dec. 14	8 M.	1737	☉	March 1	4 A.
1708	☽	Sept. 29	9 A.	1737	☽	Sept. 9	4 M.
1709	☉	March 11	2 A.	1738	☉	Aug. 15	11 M.
1710	☽	Feb. 13	11 A.	1739	☽	Jan. 24	11 A.
1710	☉	Feb. 28	1 A.	1739	☉	Aug. 4	5 A.
1711	☉	July 16	8 A.	1739	☉	Dec. 30	9 M.
1711	☽	July 29	6 A. T.	1740	☽	Jan. 13	11 A. T.
1712	☽	Jan. 23	8 A.	1741	☽	Jan. 1	2 A.
1713	☽	June 8	6 A.	1743	☽	Nov. 2	3 M. T.
1713	☽	Dec. 2	4 M.	1744	☽	Aug. 26	9 A.
1715	☉	May 3	9 M. T.	1746	☽	Aug. 30	12 A.
1715	☽	Nov. 11	5 M.	1747	☽	Feb. 14	5 M. T.
1717	☽	March 27	3 M.	1748	☉	July 25	11 M.
1717	☽	May 20	6 A.	1748	☽	Aug. 8	12 A.
1718	☽	Sept. 9	8 A. T.	1749	☽	Dec. 23	8 A.
1719	☽	Aug. 29	9 A.	1750	☉	Jan. 8	9 M.
1721	☽	Jan. 13	3 A.	1750	☽	June 19	9 A. T.
1722	☽	June 29	3 M.	1750	☽	Dec. 13	7 M.
1722	☉	Dec. 8	3 A.	1751	☽	June 9	2 M.
1722	☽	Dec. 22	4 A.	1751	☽	Dec. 2	10 M.
1724	☉	May 22	7 A. T.	1752	☉	May 13	8 A.
1724	☽	Nov. 1	4 M.	1753	☽	April 17	7 A.
1725	☽	Oct. 21	7 A.	1753	☉	Oct. 26	10 M.
1726	☉	Sept. 25	6 A.	1755	☽	March 28	1 M.
1726	☽	Oct. 11	5 M.	1757	☽	Feb. 4	6 M.
1727	☉	Sept. 15	7 M.	1757	☽	July 30	12 A.
1729	☽	Feb. 13	9 A. T.	1758	☽	Jan. 24	7 M. T.

Visible Eclipses from 1700 *to* 1800.

After Christ.		Months and days.	Time of the day or night.	After Christ.		Months and days.	Time of the day or night.
1758	☉	Dec. 30	7 M.	1779	☽	May 30	5 M. T.
1759	☉	June 24	7 A.	1779	☉	June 14	8 M.
1759	☉	Dec. 19	2 A.	1779	☽	Nov. 23	8 A.
1760	☽	May 29	7 A.	1780	☉	Oct. 27	6 A.
1760	☉	June 13	9 M.	1780	☽	Nov. 12	4 M.
1760	☽	Nov. 22	9 A.	1781	☉	April 23	6 A.
1761	☽	May 18	11 A. T.	1781	☉	Oct. 17	8 M.
1762	☽	May 8	4 M.	1782	☽	April 12	7 A.
1762	☉	Oct. 17	8 M.	1783	☽	March 18	9 A. T.
1762	☽	Nov. 1	8 A.	1783	☽	Sept. 10	11 A. T.
1763	☉	April 13	8 M.	1784	☽	March 7	3 M.
1764	☉	April 1	10 M.	1785	☉	Feb. 9	1 A.
1764	☽	April 16	1 M.	1787	☽	Jan. 3	12 A. T.
1765	☉	March 21	2 A.	1787	☉	Jan. 19	10 M.
1765	☉	Aug. 16	5 A.	1787	☉	June 15	5 A.
1766	☽	Feb. 24	7 A.	1787	☽	Dec. 24	3 A.
1766	☉	Aug. 5	7 A.	1788	☉	June 4	9 M.
1768	☽	Jan. 4	5 M.	1789	☽	Nov. 2	12 A.
1768	☽	June 30	4 M. T.	1790	☽	April 28	12 A. T.
1768	☽	Dec. 23	4 A. T.	1790	☽	Oct. 23	1 M. T.
1769	☉	June 4	8 M.	1791	☉	April 3	1 A.
1769	☽	Dec. 13	7 M.	1791	☽	Oct. 12	3 M.
1770	☉	Nov. 17	10 M.	1792	☉	Sept. 16	11 M.
1771	☽	April 28	2 M.	1793	☽	Feb. 25	10 A.
1771	☽	Oct. 23	3 A.	1793	☉	Sept. 5	3 A.
1772	☽	Oct. 11	6 A. T.	1794	☉	Jan. 31	4 A.
1772	☉	Oct. 26	10 M.	1794	☽	Feb. 14	11 A. T.
1773	☉	March 23	5 M.	1794	☉	Aug. 25	5 A.
1773	☽	Sept. 30	7 A.	1795	☽	Feb. 4	1 M.
1774	☉	March 12	10 M.	1795	☉	July 16	9 M.
1776	☽	July 31	1 M. T.	1795	☽	July 31	8 A.
1776	☉	Aug. 14	5 M.	1797	☉	June 25	8 A.
1777	☉	Jan. 9	5 A.	1797	☽	Dec. 4	6 M. T.
1778	☉	June 24	4 A.	1798	☽	May 27	7 A. T.
1778	☽	Dec. 4	6 M.	1800	☽	Oct. 2	11 A.

* See the supplementary chapter on eclipses, vol. ii, for a catalogue of eclipses from 1800 to 1900.

328. *A List of Eclipses, and Historical Events, which happened about the same time, from Ricciolus.*

Before Christ.		
754	July 5.	But according to an old calendar, this eclipse of the Sun was on the 21st of April, on which day the foundations of Rome were laid; if we may believe Tarantius Firmanus.
721	Mar. 19.	A total eclipse of the Moon. The Assyrian empire at an end; the Babylonian established.
585	May 28.	An eclipse of the Sun foretold by Thales, by which a peace was brought about between the Medes and Lydians.
523	July 16.	An eclipse of the Moon, which was followed by the death of Cambyses.
502	Nov. 19.	An eclipse of the Moon, which was followed by the slaughter of the Sabines and the death of Valerius Publicola.
463	April 30.	An eclipse of the Sun. The Persian war, and the falling off of the Persians from the Egyptians.
431	April 25.	An eclipse of the Moon, which was followed by a great famine at Rome, and the beginning of the Peloponnesian war.
431	Aug. 3.	A total eclipse of the Sun. A comet and plague at Athens.[a]
413	Aug. 27.	A total eclipse of the Moon. Nicias with his ship destroyed at Syracuse.
394	Aug. 14.	An eclipse of the Sun. The Persians beat by Conon in a sea engagement.
168	June 21.	A total eclipse of the Moon. The next day Perseus king of Macedonia was conquered by Paulus Emilius.

After Christ.		
59	April 30.	An eclipse of the Sun. This is reckoned among the prodigies, on account of the murder of Agrippinus by Nero.
237	April 12.	A total eclipse of the Sun. A sign that the reign of the Gordiani would not continue long. A sixth persecution of the christians.
306	July 27.	An eclipse of the Sun. The stars were seen, and the emperor Constantius died.
840	May 4.	A dreadful eclipse of the Sun. Lewis the Pious died within six months after it.
1009	——	An eclipse of the Sun. Jerusalem taken by the Saracens.
1133	Aug. 2.	A terrible eclipse of the Sun. The stars were seen. A schism in the church, occasioned by there being three Popes at once.

a This eclipse happened in the first year of the Peloponnesian war.

329. I have not cited one half of Ricciolus's list of portentous eclipses; and for the same reason that he declines giving any more of them than what that list contains; namely, that it is most disagreeable to dwell any longer on such nonsense, and as much as possible to avoid tiring the reader: the superstition of the ancients may be seen by the few here copied. My author farther says, that there were treatises written to shew against what regions the malevolent effects of any particular eclipse were aimed: and the writers affirmed, that the effects of an eclipse of the Sun continued as many years as the eclipse lasted hours; and that of the Moon as many months.

The superstitious notions of the ancients with regard to eclipses.

330. Yet such idle notions were once of no small advantage to Christopher Columbus, who, in the year 1493, was driven on the island of Jamaica, where he was in the greatest distress for want of provisions, and was moreover refused any assistance from the inhabitants; on which he threatened them with a plague, and told them, that in token of it there should be an eclipse; which accordingly fell on the day he had foretold, and so terrified the barbarians, that they strove who should be first in bringing him all sorts of provisions, throwing them at his feet, and imploring his forgiveness. Ricciolus's Almagest, vol. i, l. v, c. ii.

Very fortunate once for Christopher Columbus.

331. Eclipses of the Sun are more frequent than those of the Moon, because the Sun's ecliptic limits are greater than the Moon's, § 317: yet we have more visible eclipses of the Moon than of the Sun, because eclipses of the Moon are seen from all parts of that hemisphere of the Earth which is next her, and are equally great to each of those parts; but the Sun's eclipses are visible only to that small portion of the hemisphere next him whereon the Moon's shadow falls; as shall be explained by and by at large.

Why there are more visible eclipses of the Moon than of the Sun.

332. The Moon's orbit being elliptical, and the Earth in one of its foci, she is once at her least distance from the Earth, and once at her greatest in every lunation. When the Moon changes at her least distance from the Earth, and so near the node that her dark shadow falls upon the Earth, she appears big enough to cover the whole[4] disc of the Sun from that part

[4] Although the Sun and Moon are spherical bodies, as seen from the Earth, they appear to be circular planes; and so would the Earth do, if it were seen from the

Total and annular eclipses of the Sun. Plate XI.

on which her shadow falls; and the Sun appears totally eclipsed there, as at *A*, for some minutes: but when the Moon changes at her greatest distance from the Earth, and so near the node that her dark shadow is directed towards the Earth, her diameter subtends a less angle than the Sun's; and therefore she cannot hide his whole disc from any part of the Earth, nor does her shadow reach it at that time; and to the place over which the point of her shadow hangs, the eclipse is annular, as at *B*; the Sun's edge appearing like a luminous ring all around the body of the Moon. When the change happens within 17 degrees of the node, and the Moon at her mean distance from the Earth, the point of her shadow just touches the Earth, and she eclipses the Sun totally to that small spot whereon her shadow falls; but the darkness is not of a moment's continuance.

The longest duration of total eclipses of the Sun.

333. The Moon's apparent diameter when largest exceeds the Sun's when least, only 1 minute 38 seconds of a degree: and in the greatest eclipse of the Sun that can happen at any time and place, the total darkness continues no longer than whilst the Moon is going 1 minute 38 seconds from the Sun in her orbit, which is about 3 minutes and 13 seconds of an hour.[5]

To how much of the Earth the Sun may be totally or partially eclipsed at once.

334. The Moon's dark shadow covers only a spot on the Earth's surface, about 180 English miles broad, when the Moon's diameter appears largest and the Sun's least; and the total darkness can extend no farther than the dark shadow covers. Yet the Moon's partial shadow or penumbra may then cover a circular space 4900 miles in diameter, within all which the Sun is more or less eclipsed, as the places are less or more distant from the centre of the penumbra. When the Moon changes exactly in the node, the penumbra is circular on the Earth at the middle of the general eclipse; because at that time it falls perpendicularly on the Earth's surface; but at every other moment it falls obliquely, and will therefore be elliptical,

Moon. The apparently flat surfaces of the Sun and Moon are called their *discs* by astronomers.

[5] It appears from the accurate observations of modern astronomers that the Sun's apparent diameter when smallest is 31′ 29″, and that the Moon's diameter when largest is 33′ 34″. Total darkness, therefore, may continue 4 minutes 6 seconds, as in this time the Moon moves through the space of 2′ 5″, the difference between the Moon's greatest and the Sun's least diameter.—*Ed.*

and the more so, as the time is longer before or after the middle of the general eclipse; and then much greater portions of the Earth's surface are involved in the penumbra.

335. When the penumbra first touches the Earth, the general eclipse begins: when it leaves the Earth, the general eclipse ends: from the beginning to the end the Sun appears eclipsed in some part of the Earth or other. When the penumbra touches any place, the eclipse begins at that place, and ends when the penumbra leaves it. When the Moon changes in the node, the penumbra goes over the centre of the Earth's disc as seen from the Moon; and consequently, by describing the longest line possible on the Earth, continues the longest upon it; namely, at a mean rate, 5 hours 50 minutes; more, if the Moon be at her greatest distance from the Earth, because she then moves slowest; less, if she be at her least distance, because of her quicker motion.

Duration of general and particular eclipses.

336. To make the last five articles and several other phenomena plainer, let *S* be the Sun, *E* the Earth, *M* the Moon, and *A M P* the Moon's orbit. Draw the right line *W c* 12 from the western side of the Sun at *W*, touching the western side of the Moon at *c*, and the Earth at 12; draw also the right line *V d* 12 from the eastern side of the Sun at *V*, touching the eastern side of the Moon at *d*, and the Earth at 12: the dark space *c e* 12 *d* included between those lines is the Moon's shadow, ending in a point at 12, where it touches the Earth; because in this case the Moon is supposed to change at *M* in the middle between *A* the apogee, or farthest point of her orbit from the Earth, and *P* the perigee, or nearest point to it. For, had the point *P* been at *M*, the Moon had been nearer the Earth; and her dark shadow at *e* would have covered a space upon it about 180 miles broad, and the Sun would have been totally darkened, as at *A* (Fig. 1), with some continuance: but had the point *A* (Fig. 2), been at *M*, the Moon would have been farther from the Earth, and her shadow would have ended in a point about *e*, and therefore the Sun would have appeared, as at *B* (Fig. 1), like a luminous ring all around the Moon. Draw the right lines *W X d h* and *V X c g*, touching the contrary sides of the Sun and Moon, and ending on the Earth at *a* and *b*: draw also the right line *S X M* 12, from the centre of the Sun's disc,

Plate XI. Fig. 2.

The Moon's dark shadow, and penumbra.

through the Moon's centre to the Earth at 12; and suppose the two former lines $W X d h$ and $V X c g$ to revolve on the line $S X M$ 12 as an axis, and their points a and b will describe the limits of the penumbra $T T$ on the Earth's surface, including the large space a 0 b 12 a; within which the Sun appears more or less eclipsed, as the places are more or less distant from the verge a 0 b of the penumbra.

Digits, what.

Draw the right line y 12 across the Sun's disc, perpendicular to $S X M$, the axis of the penumbra then divide the line y 12 into twelve equal parts, as in the figure for the twelve digits of the Sun's diameter: and at equal distances from the centre of the penumbra at 12 (on the Earth's surface $Y Y$) to its edge a 0 b, draw twelve concentric circles, as marked with the numeral figures 1 2 3 4, &c. and remember that the Moon's motion in her orbit $A M P$ is from west to east, as from s to t. Then,

The different phases of a solar eclipse.

To an observer on the Earth at b, the eastern limb of the Moon at d seems to touch the western limb of the Sun at W, when the Moon is at M, and the Sun's eclipse begins at b, appearing as at A in Fig 3 at the left hand; but, at the same moment of absolute time to an observer at a in Fig. 2, the western edge of the Moon at c leaves the eastern edge of the Sun at V, and the eclipse ends, as at the right hand C of Fig. 3. At the very same instant, to all those who live on the circle marked 1 on the Earth E in Fig. 2, the Moon M cuts off or darkens a twelfth part of the Sun S, and eclipses him one digit, as at 1 in Fig. 3: to those who live on the circle marked 2 in Fig. 2, the Moon cuts off two twelfth parts of the Sun, as at 2 in Fig. 3: to those on the circle 3, three parts; and so on to the centre at 12 in Fig. 2, where the Sun is centrally eclipsed,

Fig. 3.

as at B in the middle of Fig. 3; under which figure there is a scale of hours and minutes, to shew at a mean state how long it is from the beginning to the end of a central eclipse of the Sun on the parallel of London; and how many digits are eclipsed at any particular time from the beginning at A to the middle at B, or the end at C. Thus, in 16 minutes from the beginning, the Sun is two digits eclipsed; in an hour and five minutes, eight digits; and in an hour and thirty-seven minutes, 12 digits.

337. By Fig. 2 it is plain, that the Sun is totally or centrally

eclipsed but to a small part of the Earth at any time; because the dark conical shadow *e* of the Moon *M* falls but on a small part of the Earth: and that the partial eclipse is confined at that time to the space included by the circle *a O b*, of which only one-half can be projected in the figure, the other half being supposed to be hid by the convexity of the Earth *E*: and likewise, that no part of the Sun is eclipsed to the large space *Y Y* of the Earth, because the Moon is not between the Sun and any of that part of the Earth: and therefore to all that part the eclipse is invisible. The Earth turns eastward on its axis, as from *g* to *h*, which is the same way that the Moon's shadow moves: but the Moon's motion is much swifter in her orbit from *s* to *t*: and therefore, although eclipses of the Sun are of longer duration, on account of the Earth's motion on its axis, than they would be if that motion was stopped, yet in four minutes of time at most, the Moon's swifter motion carries her dark shadow quite over any place that its centre touches at the time of greatest obscuration. The motion of the shadow on the Earth's disc is equal to the Moon's motion from the Sun, which is about 30½ minutes of a degree every hour at a mean rate; but so much of the Moon's orbit is equal to 30½ degrees of a great circle on the Earth, § 320, and therefore the Moon's shadow goes 30½ degrees, or 1830 geographical miles on the Earth in an hour, or 30½ miles in a minute, which is almost four times as swift as the motion of a cannon ball.

Fig. 2.

The velocity of the Moon's shadow on the Earth.

338. As seen from the Sun or Moon, the Earth's axis appears differently inclined every day of the year, on account of keeping its parallelism throughout its annual course. Let *E*, *D*, *O*, *N*, be the Earth at the two equinoxes and the two solstices, *N S* its axis, *N* the north pole, *S* the south pole, *Æ Q* the equator, *T* the tropic of Cancer, *t* the tropic of Capricorn, and *A B C* the circumference of the Earth's enlightened disc as seen from the Sun or new moon at these times. The Earth's axis has the position *N E S* at the vernal equinox, lying towards the right hand, as seen from the Sun or new moon; its poles *N* and *S* being then in the circumference of the disc; and the equator and all its parallels seem to be straight lines, because their planes pass through the observer's eye looking down upon the Earth from the Sun or Moon directly over *E*,

Fig. 4.

Phenomena of the Earth as seen from the Sun or new moon at different times of the year.

where the ecliptic *F G* intersects the equator *Æ*. At the summer solstice, the Earth's axis has the position *N D S*; and that part of the ecliptic *F G*, in which the Moon is then new, touches the tropic of Cancer *T* at *D*. The north pole *N* at that time inclining 23½ degrees towards the Sun, falls so many degrees within the Earth's enlightened disc, because the Sun is then vertical to *D*, 23½ degrees north of the equator *Æ Q*; and the equator with all its parallels seem elliptic curves bending downward, or toward the south pole, as seen from the Sun: which pole, together with 23½ degrees all round it, is hid behind the disc in the dark hemisphere of the Earth. At the autumnal equinox, the Earth's axis has the position *N O S*, lying to the left hand as seen from the Sun or new moon, which are then vertical to *O*, where the ecliptic cuts the equator *Æ Q*. Both poles now lie in the circumference of the disc, the north pole just going to disappear behind it, and the south pole just entering into it; and the equator, with all its parallels, seem to be straight lines, because their planes pass through the observer's eye, as seen from the Sun, and very nearly so as seen from the Moon. At the winter solstice, the Earth's axis has the position *N N S*, when its south pole *S*, inclining 23½ degrees towards the Sun, falls 23½ degrees within the enlightened disc, as seen from the Sun or new Moon, which are then vertical to the tropic of Capricorn *t*, 23½ degrees south of the equator *Æ Q*; and the equator, with all its parallels, seem elliptic curves bending upward; the north pole being as far hid behind the disc in the dark hemisphere, as the south pole is come into the light. The nearer that any time of the year is to the equinoxes or solstices, the more it partakes of the phenomena relating to them.

Various positions of the Earth's axis as seen from the Sun at different times of the year.

339. Thus it appears, that from the vernal equinox to the autumnal, the north pole is enlightened; and the equator and all its parallels appear elliptical as seen from the Sun, more or less curved as the time is nearer to or farther from the summer solstice; and bending downwards, or towards the south pole; the reverse of which happens from the autumnal equinox to the vernal. A little consideration will be sufficient to convince the reader, that the Earth's axis inclines towards the Sun at the summer solstice; from the Sun at the winter solstice; and sidewise to the Sun at the equinoxes; but towards the right hand, as seen from the Sun at the vernal equinox; and towards

the left hand at the autumnal. From the winter to the summer solstice, the Earth's axis inclines more or less to the right hand, as seen from the Sun; and the contrary from the summer to the winter solstice.

240. The different positions of the Earth's axis, as seen from the Sun at different times of the year, affect solar eclipses greatly with regard to particular places; so far indeed as would make central eclipses which fall at one time of the year invisible if they fell at another, even though the Moon should always change in the nodes, and at the same hour of the day: of which indefinitely various affections, we shall only give examples for the times of the equinoxes and solstices.

How these positions affect solar eclipses.

In the same diagram, let *F G* be part of the ecliptic, and *I K*, *i k*, *i k*, *i k*, part of the Moon's orbit, both seen edgewise, and therefore projected into right lines; and let the intersections *N*, *O*, *D*, *E*, be one and the same node at the above times, when the Earth has the fore-mentioned different positions: and let the spaces included by the circles, *P*, *p*, *p*, *p*, be the penumbra at these times, as its centre is passing over the centre of the Earth's disc. At the winter solstice, when the Earth's axis has the position *N N S*, the centre of the penumbra *P* touches the tropic of Capricorn *t* in *N* at the middle of the general eclipse; but no part of the penumbra touches the tropic of Cancer *T*. At the summer solstice, when the Earth's axis has the position *N D S* (*i D k* being then part of the Moon's orbit, whose node is at *D*), the penumbra *p* has its centre at *D*, on the tropic of Cancer *T*, at the middle of the general eclipse, and then no part of it touches the tropic of Capricorn *t*. At the autumnal equinox, the Earth's axis has the position *N O S* (*i O k* being then part of the Moon's orbit), and the penumbra equally includes part of both tropics *T* and *t* at the middle of the general eclipse: at the vernal equinox it does the same, because the Earth's axis has the position *N E S*: but, in the former of these two last cases, the penumbra enters the Earth at *A*, north of the tropic of Cancer *T*, and leaves it at *m*, south of the tropic of Capricorn *t*; having gone over the Earth obliquely southward, as its centre described the line *A O m*: whereas, in the latter case, the penumbra touches the Earth at *n*, south of the equator *Æ Q*, and describing the line *n E q* (similar to the former line *A O m*, in open space), goes obliquely

Fig. 4.

northward over the Earth, and leaves it at *q*, north of the equator.

In all these circumstances, the Moon has been supposed to change at noon in her descending node: had she changed in her ascending node, the phenomena would have been as various the contrary way, with respect to the penumbra's going northward or southward over the Earth. But because the Moon changes at all hours, as often in one node as in the other, and at all distances from them both at different times as it happens, the variety of the phases of eclipses are almost innumerable, even at the same places; considering also how variously the same places are situated on the enlightened disc of the Earth, with respect to the penumbra's motion at the different hours when eclipses happen.

How much of the penumbra falls on the Earth at different distances from the nodes.

341. When the Moon changes 17 degrees short of her descending node, the penumbra *P* 18 just touches the northern part of the Earth's disc, near the north pole *N*; and, as seen from that place, the Moon appears to touch the Sun, but hides no part of him from sight. Had the change been as far short of the ascending node, the penumbra would have touched the southern part of the disc near the south pole *S*. When the Moon changes 12 degrees short of the descending node, more than a third part of the penumbra *P* 12 falls on the northern parts of the Earth at the middle of the general eclipse: had she changed as far past the same node, as much of the other side of the penumbra about *P* would have fallen on the southern part of the Earth; all the rest in the *expansum* or open space. When the Moon changes 6 degrees from the node, almost the whole penumbra *P* 6 falls on the Earth at the middle of the general eclipse. And, lastly, when the Moon changes in the node at *N*, the penumbra *P N* takes the longest course possible on the Earth's disc; its centre falling on the middle thereof, at the middle of the general eclipse. The farther the Moon changes from either node, within 17 degrees of it, the shorter is the penumbra's continuance on the Earth, because it goes over a less portion of the disc, as is evident by the figure.

The Earth's diurnal motion lengthens the duration of solar

342. The nearer that the penumbra's centre is to the equator at the middle of the general eclipse, the longer is the duration of the eclipse at all those places where it is central; because, the nearer that any place

is to the equator, the greater is the circle it describes by the Earth's motion on its axis: and so, the place moving quicker, keeps longer in the penumbra, whose motion is the same way with that of the place, though faster, as been already mentioned, § 337. Thus (see the Earth at and the penumbra at 12), whilst the point *b* in the polar circle *a b c d* is carried from *b* to *c* by the Earth's diurnal motion, the point *d* on the tropic of Cancer *T* is carried a much greater length from *d* to *D*; and therefore, if the penumbra's centre goes one time over *C* and another time over *D*, the penumbra will be longer in passing over the moving place *d* than it was in passing over the moving place *b*. Consequently, central eclipses about the poles are of the shortest duration; and about the equator the longest.

eclipses which fall without the polar circles.

343. In the middle of summer, the whole frigid zone included by the polar circle *a b c d* is enlightened; and if it then happens that the penumbra's centre goes over the north pole, the Sun will be eclipsed much the same number of digits at *a* as at *c*; but whilst the penumbra moves eastward over *c*, it moves westward over *a*, because, with respect to the penumbra, the motions of *a* and *c* are contrary; for *c* moves the same way with the penumbra towards *d*, but *a* moves the contrary way towards *b*; and therefore the eclipse will be of longer duration at *c* than at *a*. At *a* the eclipse begins on the Sun's eastern limb, but at *c* on his western: at all places lying without the polar circles, the Sun's eclipses begin on his western limb, or near it, and end on or near his eastern. At those places where the penumbra touches the Earth, the eclipse begins with the rising Sun, on the top of his western or uppermost edge; and at those places where the penumbra leaves the Earth, the eclipse ends with the setting Sun, on the top of his eastern edge, which is then the uppermost, just at its disappearing in the horizon.

And shortens the duration of some which fall within these circles.

344. If the Moon were surrounded by an atmosphere of any considerable density, it would seem to touch the Sun a little before the Moon made her appulse to his edge, and we should see a little faintness on that edge before it were eclipsed by the Moon: but as no such faintness has been observed, at least so far as I ever heard, it seems plain that the Moon has no such atmosphere as that of the Earth. The faint ring of light surrounding the Sun in

The Moon has no atmosphere.

total eclipses, called by Cassini *la Chevelure du Soleil*, seems to be the atmosphere of the Sun, because it has been observed to move equally with the Sun, and not with the Moon. (See § 58, Note.)

Eclipses of the Moon. 345. Having been so prolix concerning eclipses of the Sun, we shall drop that subject at present, and proceed to the doctrine of lunar eclipses, which, being more simple, may be explained in less time.

That the Moon can never be eclipsed but at the time of her being full, and the reason why she is not eclipsed at every full, has been shewn already, § 316, 317. Plate XI. Fig. 2. Let *S* be the Sun, *E* the Earth, *R R* the Earth's shadow, and *B* the Moon in opposition to the Sun: in this situation the Earth intercepts the Sun's light in its way to the Moon; and when the Moon touches the Earth's shadow at *v*, she begins to be eclipsed on her eastern limb *x*, and continues eclipsed until her western limb *y* leaves the shadow at *z*: at *B* she is in the middle of the shadow, and consequently in the middle of the eclipse.

346. The Moon, when totally eclipsed, is not invisible, if she be above the horizon, and the sky be clear; but appears generally of a dusky colour, like tarnished copper, which some have thought to be the Moon's native light. Why the Moon is visible in a total eclipse. But the true cause of her being visible is the scattered beams of the Sun, bent into the Earth's shadow by going through the atmosphere, which, being more dense near the Earth than at considerable heights above it, refracts or bends the Sun's rays more inward, § 179, the nearer they are passing by the Earth's surface, than those rays which go through higher parts of the atmosphere, where it is less dense according to its height, until it be so thin or rare as to lose its refractive power. Let the circle *f g h i*, concentric to the Earth, include the atmosphere, whose refractive power vanishes at the heights *f* and *i*; so that the rays *W f w* and *V i v* go on straight, without suffering the least refraction; but all those rays which enter the atmosphere between *f* and *k*, and between *i* and *l*, on opposite sides of the Earth, are gradually more bent inward as they go through a greater portion of the atmosphere, until the rays *W k* and *V l* touching the Earth at *m* and *n*, are bent so much as to meet at *q*, a little short of the Moon; and therefore the dark sha-

dow of the Earth is contained in the space *moqpn*, where none of the Sun's rays can enter: all the rest *RR*, being mixed by the scattered rays which are refracted as above, is in some measure enlightened by them; and some of those rays falling on the Moon, give her the colour of tarnished copper, or of iron almost red hot. So that if the Earth had no atmosphere, the Moon would be as invisible in total eclipses as she is when new. If the Moon were so near the Earth as to go into its dark shadow, suppose about *po*, she would be invisible during her stay in it, but visible before and after in the fainter shadow *RR*.[*]

Why the Sun and Moon are sometimes visible when the Moon is totally eclipsed.

347. When the Moon goes through the centre of the Earth's shadow, she is directly opposite to the Sun; yet the Moon has been often seen totally eclipsed in the horizon when the Sun was also visible in the opposite part of it: for, the horizontal refraction being almost 34 minutes of a degree, § 181, and the diameter of the Sun and Moon being each at a mean state but 32 minutes, the refraction causes both luminaries to appear above the horizon when they are really below it, § 179.

Fig. 5.

348. When the Moon is full at 12 degrees from either of her nodes, she just touches the Earth's shadow, but does not enter into it. Let *GH* be the ecliptic; *ef* the Moon's orbit where she is 12 degrees from the node at her full, *cd* her orbit where she is 6 degrees from the node; *ab* her orbit where she is full in the node; *AB* the Earth's shadow, and *M* the Moon. When the Moon describes the line *ef*, she just touches the shadow, but does not enter into it;

* The explanation here given by Mr. Ferguson is no doubt satisfactory, in so far as regards the luminous appearance of the Moon; but the red copper colour which she assumes still requires explanation. When a beam of white light passes through a long track of air, it always inclines to a red colour. The blue or most refrangible rays moving with less momentum, are stopped in their course, while the red rays being least refrangible, and moving with greater momentum, will easily penetrate the resisting medium. This is evident also from the appearance of the Sun and Moon in the horizon; from the red colour of the morning and evening clouds; from the redness of the sea at great depths as seen by divers, and from the appearance of luminous objects in a foggy night. Now the light which passes through the atmosphere at *m* and *n*, (Plate XI, Fig. 2), moves through the longest possible track of air, and therefore must emerge from the atmosphere of a deeper red colour than the light which reddens the morning and evening clouds. This red light being refracted by the atmosphere, is bent into the Earth's shadow, and causes that ruddy copper hue which the Moon generally assumes in lunar eclipses.—*Ed.*

when she describes the line *c d*, she is totally, though not centrally, immersed in the shadow; and when she describes the line *a b*, she passes by the node at *M* in the centre of the shadow, and takes the longest line possible, which is a diameter, through it: and such an eclipse being both total and central, is of the longest duration, namely, 3 hours 57 minutes 6 seconds from the beginning to the end, if the Moon be at her greatest distance from the Earth: and 3 hours 37 minutes 26 seconds, if she be at her least distance. The reason of this difference is, that when the Moon is farthest from the Earth, she moves slowest; and when nearest to it, quickest.

Duration of central eclipses of the Moon.

349. The Moon's diameter, as well as the Sun's, is supposed to be divided into twelve equal parts, called *Digits*;[3] and so many of these parts as are darkened by the Earth's shadow, so many digits is the Moon eclipsed. All that the Moon is eclipsed above 12 digits, shew how far the shadow of the Earth is over the body of the Moon, on that edge to which she is nearest at the middle of the eclipse.

Digits.

350. It is difficult to observe exactly either the beginning or ending of a lunar eclipse, even with a good telescope; because the Earth's shadow is so faint and ill-defined about the edges, that when the Moon is either just touching or leaving it, the obscuration of her limb is scarce sensible; and therefore the nicest observers can hardly be certain to four or five seconds of time. But both the beginning and ending of solar eclipses are visibly instantaneous; for the moment that the edge of the Moon's disc touches the Sun's, his roundness seems a little broken on that part; and the moment she leaves it, he appears perfectly round again.

Why the beginning and end of a lunar eclipse is so difficult to be determined by observation.

351. In astronomy, eclipses of the Moon are of great use for ascertaining the periods of her motions; especially such eclipses as are observed to be alike in all circumstances, and have long intervals of time between them. In geography, the longitudes of places are found by eclipses, as already shewn in the eleventh chapter: but for this purpose eclipses of the Moon are more

The use of eclipses in astronomy, geography, and chronology.

[3] *Digits* are now frequently called *Degrees*, each of which is subdivided into 60 minutes. So that the magnitude of eclipses is measured in degrees and minutes.—*Ed.*

useful than those of the Sun, because they are more frequently visible, and the same lunar eclipse is of equal largeness and duration at all places where it is seen. In chronology, both solar and lunar eclipses serve to determine exactly the time of past event: for there are so many particulars observable in every eclipse, with respect to its quantity, the places where it is visible (if of the Sun), and the time of the day or night, that it is impossible there can be two solar eclipses in the course of many ages which are alike in all circumstances.

352. From the above explanation of the doctrine of eclipses, it is evident, that the darkness at our Saviour's crucifixion was supernatural. For he suffered on the day on which the passover was eaten by the Jews, on which day it was impossible that the Moon's shadow could fall on the Earth; for the Jews kept the passover at the time of full moon: nor does the darkness in total eclipses of the Sun last above four minutes in any place, § 333; whereas the darkness at the crucifixion lasted three hours, Matt. xxvii, 15, and overspread at least all the land of Judea.

The darkness at our Saviour's crucifixion supernatural.

CHAP. XIX.

SHEWING THE PRINCIPLES ON WHICH THE FOLLOWING ASTRONOMICAL TABLES ARE CONSTRUCTED, AND THE METHOD OF CALCULATING THE TIMES OF NEW AND FULL MOONS AND ECLIPSES BY THEM.

353. The nearer that any object is to the eye of an observer, the greater is the angle under which it appears: the farther from the eye, the less.

The diameters of the Sun and Moon subtend different angles at different times. And, at equal intervals of time, these angles are once at the greatest, and once at the least, in somewhat more than a complete revolution of the luminary through the ecliptic, from any given fixed star to the same star again.—This proves that the Sun and Moon are constantly changing their distances from the Earth; and that they are once at their greatest distance, and once at their least, in little more than a complete revolution.

The gradual differences of these angles are not what they would be if the luminaries moved in circular orbits, the Earth being supposed to be placed at some distance from the centre: but they agree perfectly with elliptic orbits, supposing the lower focus of each orbit to be at the centre of the Earth.

The farthest point of each orbit from the Earth's centre is called the *apogee*, and the nearest point is called the *perigee*.—These points are directly opposite to each other.

Astronomers divide each orbit into 12 equal parts, called *signs*; each sign into 30 equal parts, called *degrees*; each degree into 60 equal parts, called *minutes*; and every minute into 60 equal parts, called *seconds*. The distance of the Sun or Moon from any given point of its orbit, is reckoned in signs, degrees, minutes, and seconds. Here we mean the distance that the luminary has moved through from any given point; not the space it is short thereof in coming round again, though ever so little.

The distance of the Sun or Moon from its apogee, at any given time, is called its *mean anomaly*; so that, in the apogee, the anomaly is nothing; in the perigee, it is six signs.

The motions of the Sun and Moon are observed to be continually accelerated from the apogee to the perigee, and as gradually retarded from the perigee to the apogee; being slowest of all when the mean anomaly is nothing, and swiftest of all when it is six signs.

When the luminary is in its apogee or perigee, its place is the same as it would be if its motion were equable in all parts of its orbit. The supposed equable motions are called *mean*, the unequable are justly called the *true*.

The mean place of the Sun or Moon is always forwarder than the true place,* whilst the luminary is moving from its apogee to its perigee; and the true place is always forwarder than the mean, whilst the luminary is moving from its perigee to its apogee. In the former case, the anomaly is always less than six signs; and in the latter case, more.

It has been found, by a long series of observations, that the Sun goes through the ecliptic, from the vernal equinox to the same equinox again, in 365 days 5 hours 48 minutes 55 se-

* The point of the ecliptic in which the Sun or Moon is at any given moment of time, is called the *place* of the Sun or Moon at that time.

conds: from the first star of Aries to the same star again, in 365 days 6 hours 9 minutes 24 seconds: and from his apogee to the same again, in 365 days 6 hours 14 minutes 0 seconds. —The first of these is called the *solar year*, the second the *sydereal year*, and the third the *anomalistic year*. So that the solar year is 20 minutes 29 seconds shorter than the sydereal; and the sydereal year is 4 minutes 36 seconds shorter than the anomalistic. Hence it appears, that the equinoctial point, or intersection of the ecliptic and equator at the beginning of Aries, goes backward with respect to the fixed stars, and that the Sun's apogee goes forward.

It is also observed, that the Moon goes through her orbit, from any given fixed star to the same star again, in 27 days 7 hours 43 minutes 4 seconds, at a mean rate; from her apogee to her apogee again, in 27 days 13 hours 18 minutes 43 seconds: and from the Sun to the Sun again, in 29 days 12 hours 41 minutes $3\frac{1}{20}$ seconds. This shews, that the Moon's apogee moves forward in the ecliptic, and that at a much quicker rate than the Sun's apogee does; since the Moon is five hours 55 minutes 39 seconds longer in revolving from her apogee to her apogee again, than from any star to the same star again.

The Moon's orbit crosses the ecliptic in two opposite points, which are called her *nodes*: and it is observed that she revolves sooner from any node to the same node again, than from any star to the same star again, by 2 hours 38 minutes 27 seconds, which shews that her nodes move backward, or contrary to the order of signs, in the ecliptic.

The time in which the Moon revolves from the Sun to the Sun again (or from change to change) is called a *lunation*; which, according to Dr. Pound's mean measures, would always consist of 29 days 12 hours 44 minutes 3 seconds 2 thirds 58 fourths, if the motions of the Sun and Moon were always equable.[2] Hence, 12 mean lunations contain 354 days 8 hours 48 minutes 36 seconds 35 thirds 40 fourths, which is 10 days 21 hours 11 minutes 23 seconds 24 thirds 20 fourths less than the length of a common Julian year, consisting of 365 days 6 hours: and 13 mean lunations contain 383 days 21 hours 32 minutes 39 seconds 38 thirds 38 fourths, which exceeds the

[2] We have thought proper to keep Dr. Pound's length of a mean lunation, because his numbers come nearer to the times of ancient eclipses, than Meyer's do, without allowing for the Moon's acceleration.

length of a common Julian year, by 18 days 15 hours 32 minutes 39 seconds 38 thirds 38 fourths.

The mean time of new moon being found for any given year and month, as suppose for March 1700, old style, if this mean new moon falls later than the 11th day of March, then, 12 mean lunations added to the time of this mean new moon will give the time of the mean new moon in March 1701, after having thrown off 365 days. But, when the mean new moon happens to be before the 11th of March, we must add 13 mean lunations, in order to have the time of mean new moon in March the year following: always taking care to subtract 365 days in common years, and 366 days in leap years, from the sum of this addition.

Thus, A. D. 1700, old style, the time of mean new moon in March was the 8th day, at 16 hours 11 minutes 25 seconds after the noon of that day (viz. at 11 minutes 25 seconds past IV in the morning of the 9th day, according to common reckoning). To this we must add 13 mean lunations, or 383 days 21 hours 32 minutes 39 seconds 38 thirds 38 fourths, and the sum will be 392 days 13 hours 44 minutes 4 seconds 38 thirds 38 fourths; from which subtract 365 days, because the year 1701 is a common year, and there will remain 27 days 13 hours 44 minutes 4 seconds 38 thirds 38 fourths for the time of mean new moon in March, A. D 1701.

Carrying on this addition and subtraction till A. D. 1703, we find the time of mean new moon in March that year to be on the 6th day, at 7 hours 21 minutes 17 seconds 49 thirds 46 fourths past noon; to which add 13 mean lunations, and the sum will be 390 days 4 hours 53 minutes 57 seconds 28 thirds 20 fourths; from which subtract 366 days, because the year 1704 is a leap year, and there will remain 24 days 4 hours 53 minutes 57 seconds 28 thirds 20 fourths, for the time of mean new moon in March, A. D. 1704.

In this manner was the first of the following tables constructed to seconds, thirds, and fourths; and then written out to the nearest seconds. The reason why we chose to begin the year with March, was to avoid the inconvenience of adding a day to the tabular time in leap years after February, or subtracting a day therefrom in January and February in those years; to which all tables of this kind are subject, which begin the year with January, in calculating the times of new or full moons.

The mean anomalies of the Sun and Moon, and the Sun's mean motion from the ascending node of the Moon's orbit, are set down in Table III, from one to 13 mean lunations.—These numbers, for 13 lunations, being added to the radical anomalies of the Sun and Moon, and to the Sun's mean distance from the ascending node, at the time of mean new moon in March 1700 (Table I), will give their mean anomalies, and the Sun's mean distance from the node, at the time of mean new moon in March 1701; and being added for 12 lunations to those for 1701, give them for the time of mean new moon in March 1702. And so on, as far as you please to continue the Table, always throwing off 12 signs when their sum exceeds 12, and setting down the remainder as the proper quantity.

If the numbers belonging to A. D. 1700 (in Table I) be subtracted from those belonging to 1800, we shall have their whole differences in 100 complete Julian years; which accordingly we find to be 4 days 8 hours 10 minutes 52 seconds 15 thirds 40 fourths, with respect to the time of mean new moon. These being added together 60 times (always taking care to throw off a whole lunation when the days exceed 29½) making up 60 centuries, or 6000 years, as in Table VI, which was carried on to seconds, thirds, and fourths; and then written out to the nearest seconds. In the same manner were the respective anomalies and the Sun's distance from the node found, for these centurial years; and then (for want of room) wrote out only to the nearest minutes, which is sufficient in whole centuries. By means of these two Tables, we may find the time of any mean new moon in March, together with the anomalies of the Sun and Moon, and the Sun's distance from the node, at these times, within the limits of 6000 years, either before or after any given year in the 18th century; and the mean time of any new or full moon in any given month after March, by means of the third and fourth Tables, within the same limits, as shewn in the precepts for calculation.

Thus it would be a very easy matter to calculate the time of any new or full moon, if the Sun and Moon moved equably in all parts of their orbits. But we have already shewn that their places are never the same as they would be by equable motions, except when they are in apogee or perigee; which is, when their mean anomalies are either nothing, or six signs: and that their mean places are always forwarder than their true places, whilst

the anomaly is less than six signs; and their true places are forwarder than the mean, whilst the anomaly is more.

Hence it is evident, that whilst the Sun's anomaly is less than six signs, the Moon will overtake him, or be opposite to him, sooner than she could if his motion were equable; and later whilst his anomaly is more than six signs. The greatest difference that can possibly happen between the mean and true time of new or full moon, on account of the inequality of the Sun's motion, is 3 hours 48 minutes 28 seconds: and that is, when the Sun's anomaly is either 3 signs 1 degree, or 8 signs 29 degrees; sooner in the first case, and later in the last. In all other signs and degrees of anomaly, the difference is gradually less, and vanishes when the anomaly is either nothing or six signs.

The Sun is in his apogee on the 30th of June, and in his perigee on the 30th of December, in the present age: so that he is nearer the Earth in our winter than in our summer. The proportional difference of distance, deduced from the difference of the Sun's apparent diameter at these times, is as 983 to 1017.

The Moon's orbit is dilated in winter, and contracted in summer; therefore, the lunations are longer in winter than in summer. The greatest difference is found to be 22 minutes 29 seconds: the lunation increasing gradually in length whilst the Sun is moving from his apogee to his perigee, and decreasing in length whilst he is moving from his perigee to his apogee.— On this account, the Moon will be later every time in coming to her conjunction with the Sun, or being in opposition to him, from December till June, and sooner from June till December, than if her orbit had continued of the same size all the year round.

As both these differences depend on the Sun's anomaly, they may be fitly put together into one Table, and called *The annual, or first equation of the mean to the true syzygy*[3] (see Table VII). This equational difference is to be subtracted from the time of the mean syzygy when the Sun's anomaly is less than six signs, and added when the anomaly is more. At the greatest, it is 4 hours 10 minutes 57 seconds, viz. 3 hours 48

[3] The word *syzygy* signifies both the conjunction and opposition of the Sun and Moon.

minutes 28 seconds, on account of the Sun's unequal motion, and 22 minutes 29 seconds, on account of the dilatation of the Moon's orbit.

This compound equation would be sufficient for reducing the mean time of new or full moon to the true time thereof, if the Moon's orbit were of a circular form, and her motion quite equable in it. But the Moon's orbit is more elliptical than the Sun's, and her motion in it so much the more unequal. The difference is so great, that she is sometimes in conjunction with the Sun, or in opposition to him, sooner by 9 hours 47 minutes 54 seconds, than she would be if her motion were equable; and at other times as much later. The former happens when her mean anomaly is 9 signs 4 degrees, and the latter when it is 2 signs 26 degrees. See Table IX.

At different distances of the Sun from the Moon's apogee, the figure of the Moon's orbit becomes different. It is longest of all, or most eccentric, when the Sun is in the same sign and degree either with the Moon's apogee or perigee; shortest of all, or least eccentric, when the Sun's distance from the Moon's apogee is either three signs or nine signs; and at a mean state when the distance is either 1 sign 15 degrees, 4 signs 15 degrees, 7 signs 15 degrees, or 10 signs 15 degrees. When the Moon's orbit is at its greatest eccentricity, her apogeal distance from the Earth's centre is to her perigeal distance therefrom, as 1067 is to 933; when least eccentric, as 1043 is to 957; and when at the mean state, as 1055 is to 945.

But the Sun's distance from the Moon's apogee is equal to the quantity of the Moon's mean anomaly at the time of new moon, and by the addition of six signs, it becomes equal in quantity to the Moon's mean anomaly at the time of full moon. Therefore, a table may be constructed so as to answer all the various inequalities depending on the different eccentricities of the Moon's orbit in the syzygies, and called *The second equation of the mean to the true syzygy* (see Table IX); and the Moon's anomaly, when equated by Table VIII, may be made the proper argument for taking out the second equation of time, which must be added to the former equated time, when the Moon's anomaly is less than six signs, and subtracted when the anomaly is more.

There are several other inequalities in the Moon's motion, which sometimes bring on the true syzygy a little sooner, and at other times keep it back a little later, than it would other-

wise be; but they are so small, that they may be all omitted except two; the former of which (see Table X) depends on the difference between the anomalies of the Sun and Moon in the syzygies, and the latter (see Table XI) depends on the Sun's distance from the Moon's nodes at these times. The greatest difference arising from the former is 4 minutes 58 seconds; and from the latter, 1 minute 34 seconds.

Having described the phenomena arising from the inequalities of the solar and lunar motions, we shall now shew the reasons of these inequalities.

In all calculations relating to the Sun and Moon, we consider the Sun as a moving body, and the Earth as a body at rest; since all the appearances are the same, whether it be the Sun or the Earth that moves. But the truth is, that the Sun is at rest, and the Earth moves round him once a-year, in the plane of the ecliptic. Therefore, whatever sign and degree of the ecliptic the Earth is in, at any given time, the Sun will then appear to be in the opposite sign and degree.

The nearer that any body is to the Sun, the more it is attracted by him; and this attraction increases as the square of the distance diminishes, and *vice versa*.

The Earth's annual orbit is elliptical, and the Sun is placed in one of its foci. The remotest point of the Earth's orbit from the Sun is called *The Earth's Aphelion*; and the nearest point of the Earth's orbit to the Sun is called *The Earth's Perihelion*. When the Earth is in its aphelion, the Sun appears to be in its apogee; and when the Earth is in its perihelion, the Sun appears to be in its perigee.

As the Earth moves from its aphelion to its perihelion, it is constantly more and more attracted by the Sun; and this attraction, by conspiring in some degree with the Earth's motion, must necessarily accelerate it. But as the Earth moves from its perihelion to its aphelion, it is continually less and less attracted by the Sun; and as this attraction acts then just as much against the Earth's motion, as it acted for it in the other half of the orbit, it retards the motion in the like degree. The faster the Earth moves, the faster will the Sun appear to move; the slower the Earth moves, the slower is the Sun's apparent motion.

The Moon's orbit is also elliptical, and the Earth keeps constantly in one of its focuses. The Earth's attraction has the same kind of influence on the Moon's motion, as the Sun's at-

traction has on the motion of the Earth: and therefore, the Moon's motion must be continually accelerated whilst she is passing from her apogee to her perigee; and is gradually retarded in moving from her perigee to her apogee.

At the time of new moon, the Moon is nearer the Sun than the Earth is at that time, by the whole semidiameter of the Moon's orbit; which, at a mean state, is 240,000 miles; and at the full, she is as much farther from the Sun than the Earth then is. Consequently, the Sun attracts the Moon more than it attracts the Earth in the former case, and less in the latter. The difference is greatest when the Earth is nearest the Sun, and least when it is farthest from him. The obvious result of this is, that as the Earth is nearest to the Sun in winter, and farthest from him in summer, the Moon's orbit must be dilated in winter, and contracted in summer.

These are the principal causes of the difference of time, that generally happens between the mean and true times of conjunction or opposition of the Sun and Moon. As to the other two differences, viz. those which depend on the difference between the anomalies of the Sun and Moon, and upon the Sun's distance from the lunar nodes, in the syzygies, they are owing to the different degrees of attraction of the Sun and Earth upon the Moon, at greater or less distances, according to their respective anomalies, and to the position of the Moon's nodes with respect to the Sun.

If ever it should happen, that the anomalies of both the Sun and Moon were either nothing or six signs, at the mean time of new or full moon, and the Sun should then be in conjunction with either of the Moon's nodes, all the above-mentioned equations would vanish, and the mean and true time of the syzygy would coincide. But if ever this circumstance did happen, we cannot expect the like again in many ages afterwards.

Every 49th lunation (or course of the Moon from change to change) returns very nearly to the same time of the day as before. For, in 49 mean lunations there are 1446 days 23 hours 58 minutes 29 seconds 25 thirds, which wants but 1 minute 30 seconds 34 thirds of 1477 days.

In 2953059085108 days, there are 100000000000 mean lunations exactly; and this is the smallest number of natural days in which any exact number of mean lunations are completed.

Table I. The mean time of New Moon in March, Old Style; with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Moon's Ascending Node, from A. D. 1700, *to* A. D. 1800 *inclusive.*

Year of Christ.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist from the Node.			
	D.	H.	M.	S.	s	°	'	"	s	°	'	"	s	°	'	"
1700	8	16	11	25	8	19	58	48	1	22	30	37	6	14	31	7
1701	27	13	44	5	9	8	20	59	0	28	7	42	7	23	11	8
1702	16	22	32	41	8	27	36	51	11	7	55	47	8	1	16	55
1703	6	7	21	18	8	16	52	43	9	17	43	52	8	9	19	42
1704	24	4	53	57	9	5	14	54	8	23	20	57	9	18	2	43
1705	13	13	42	34	8	24	30	47	7	3	9	2	9	26	5	30
1706	2	22	31	11	8	13	46	39	5	12	57	7	10	4	8	17
1707	21	20	3	50	9	2	8	50	4	18	34	13	11	12	51	18
1708	10	4	52	27	8	21	24	43	2	28	22	18	11	20	54	5
1709	29	2	25	7	9	9	46	54	2	3	59	24	0	29	37	6
1710	18	11	13	43	8	29	2	47	0	13	47	30	1	7	39	51
1711	7	20	2	20	8	18	18	39	10	23	35	36	1	15	42	41
1712	25	17	34	59	9	6	40	51	9	29	12	42	2	14	25	43
1713	15	2	23	36	8	25	56	43	8	9	0	47	3	2	28	30
1714	4	11	12	13	8	15	12	35	6	18	48	52	3	10	31	17
1715	23	8	44	52	9	3	34	47	5	24	25	57	4	19	14	18
1716	11	17	33	29	8	22	50	39	4	4	14	2	4	27	17	5
1717	1	2	22	5	8	12	6	32	2	14	2	8	5	5	19	52
1718	19	23	54	45	9	0	28	44	1	19	39	13	6	14	2	54
1719	9	8	43	22	8	19	44	37	11	29	27	18	6	22	5	41
1720	27	6	16	1	9	8	6	49	11	5	4	24	8	0	48	43
1721	16	15	4	38	8	27	22	41	9	14	52	29	8	8	51	29
1722	5	23	53	14	8	16	38	33	7	24	40	34	8	16	54	16
1723	24	21	25	54	9	5	0	45	7	0	17	40	9	25	37	18
1724	13	6	14	31	8	24	16	37	5	10	5	45	10	3	40	5
1725	2	15	3	7	8	13	32	29	3	19	53	50	10	11	42	52
1726	21	12	35	47	9	1	54	41	2	25	30	56	11	20	25	54
1727	10	21	24	23	8	21	10	34	1	5	19	1	11	28	28	41
1728	28	18	57	3	9	9	52	46	0	10	56	7	1	7	11	42
1729	18	3	45	40	8	28	48	39	10	20	44	12	1	15	14	29
1730	7	12	34	16	8	18	4	31	9	0	32	17	1	23	17	16
1731	26	10	6	56	9	6	26	42	8	6	9	23	3	2	0	17
1732	14	18	55	33	8	25	42	34	6	15	57	28	3	10	3	4

Table I. continued. Old Style.

Year of Christ	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist from the Node			
	D	H	M	S	s	°	'	"	s	°	'	"	s	°	'	"
1733	1	3	41	9	8	14	58	26	4	25	45	33	3	18	5	51
1734	25	1	16	49	9	3	20	38	4	1	22	39	4	26	48	53
1735	12	10	3	25	8	22	36	30	2	11	10	44	5	4	51	40
1736	0	18	51	2	8	11	52	22	0	20	58	49	5	12	54	27
1737	19	16	26	42	9	0	14	34	11	26	35	55	6	21	37	29
1738	9	1	15	18	8	19	30	26	10	6	24	0	6	29	40	16
1739	27	22	47	58	9	7	52	38	9	12	1	6	8	8	23	18
1740	16	7	36	31	8	27	8	30	7	21	49	11	8	16	26	5
1741	5	16	25	11	8	16	24	27	6	1	57	16	8	24	28	52
1742	24	13	57	52	9	4	16	31	5	7	14	22	10	3	11	54
1743	13	22	46	27	8	24	2	27	3	17	2	27	10	1	14	41
1744	2	7	35	4	8	13	18	20	1	26	50	32	10	19	17	28
1745	21	5	7	41	9	1	40	32	1	2	27	38	11	28	0	30
1746	10	15	56	20	8	20	56	24	11	12	15	43	0	6	3	17
1747	29	11	29	0	9	9	18	36	10	17	32	49	1	14	46	19
1748	17	20	17	36	8	28	34	28	8	27	40	54	1	22	49	5
1749	7	5	6	13	8	17	50	20	7	7	28	59	2	0	51	52
1750	26	2	38	53	9	6	12	32	6	13	6	5	3	9	34	35
1751	15	11	27	29	8	25	28	24	4	22	54	10	3	17	37	40
1752	3	20	16	6	8	14	44	16	3	2	42	15	3	25	40	27
1753	22	17	48	15	9	3	6	28	2	8	19	21	5	4	23	28
1754	12	2	37	22	8	22	22	20	0	18	7	26	5	12	26	15
1755	1	11	25	59	8	11	38	12	10	27	55	31	5	20	29	2
1756	19	8	58	38	9	0	0	24	10	5	32	37	6	29	12	3
1757	8	17	47	15	8	19	16	16	8	13	20	42	7	7	14	50
1758	27	15	19	51	9	7	38	28	7	18	57	48	8	15	57	52
1759	17	0	8	31	8	26	54	20	5	28	45	54	8	24	0	39
1760	5	8	57	8	8	16	10	12	4	8	34	0	9	2	3	26
1761	24	6	29	47	9	4	32	24	3	14	11	6	10	10	46	27
1762	13	15	18	24	8	23	48	16	1	25	59	11	10	18	49	14
1763	3	0	7	1	8	13	4	8	0	3	47	16	10	26	52	1
1764	20	21	39	40	9	1	26	20	11	9	24	21	0	5	35	2
1765	10	6	28	17	8	20	42	13	9	19	12	26	0	13	37	49
1766	29	4	0	56	9	9	4	20	8	24	49	52	1	22	20	51

Table I. concluded. Old Style.

Year of Christ.	Mean new Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
1767	18	12	49	33	8	26	20	17	7	4	37	37	2	0	23	38
1768	6	21	38	10	8	17	36	9	5	14	25	42	2	8	26	25
1769	25	19	10	40	9	5	58	21	4	20	2	48	2	17	9	27
1770	15	8	59	26	8	25	14	13	2	29	50	53	3	25	12	14
1771	4	12	48	[illegible]	8	14	30	5	1	9	38	58	4	3	15	1
1772	22	10	20	48	9	2	52	17	0	15	16	4	5	11	58	8
1773	11	19	9	19	8	22	8	9	10	25	4	9	5	20	0	50
1774	1	8	57	55	8	11	24	1	9	4	52	14	5	28	3	37
1775	20	1	30	25	8	29	46	13	8	10	29	20	7	6	49	36
1776	8	10	19	12	8	19	2	5	6	20	17	25	7	14	49	25
1777	27	7	51	51	9	7	24	17	5	25	54	31	8	23	32	26
1778	16	16	40	28	8	26	40	9	4	5	42	36	9	1	35	13
1779	6	1	29	4	8	15	56	1	2	15	30	41	9	9	38	0
1780	23	23	1	44	8	4	18	13	1	21	7	47	10	18	21	1
1781	13	7	50	21	8	23	34	5	0	0	55	52	10	26	23	48
1782	2	16	38	57	8	12	49	58	10	10	43	57	11	4	26	35
1783	21	14	11	37	9	1	12	10	9	16	21	3	0	18	9	36
1784	9	23	0	13	8	20	28	3	7	26	9	8	0	21	12	23
1785	28	20	32	53	9	8	50	15	7	1	46	14	1	29	55	25
1786	18	5	21	30	8	28	6	7	5	11	34	19	2	7	58	12
1787	7	14	10	6	8	17	21	59	3	21	22	24	2	16	0	59
1788	25	11	42	46	9	5	44	11	2	26	59	30	3	24	41	1
1789	14	20	31	23	8	25	0	3	1	6	47	35	4	2	46	48
1790	4	5	19	59	8	14	15	55	11	16	35	41	4	10	49	35
1791	23	2	52	39	9	2	38	7	10	22	12	46	5	19	32	37
1792	11	11	41	15	8	21	53	49	9	2	0	52	5	27	35	24
1793	30	9	18	55	9	10	16	11	8	7	37	58	7	6	18	26
1794	19	18	2	32	8	29	32	3	6	17	26	4	7	14	21	13
1795	9	2	51	8	8	18	47	55	4	27	14	9	7	22	24	0
1796	27	0	23	48	9	7	10	17	4	2	51	14	9	1	7	1
1797	16	9	12	24	8	26	25	59	2	12	39	19	9	9	9	48
1798	5	18	1	1	8	15	41	51	0	22	27	25	9	17	12	35
1799	24	15	23	41	9	4	4	2	11	28	4	31	10	25	55	37
1800	13	0	22	17	8	23	19	55	10	7	52	36	11	3	58	24

Table II. Mean New Moons, &c. in March, New Style, from A. D. 1752 *to* A. D. 1800.

Year of Christ.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anamoly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
1752	14	20	16	6	8	14	44	16	3	2	42	15	3	25	40	27
1753	4	5	4	42	8	4	0	8	1	12	30	20	4	3	43	14
1754	23	2	37	22	8	22	22	20	0	18	7	26	5	12	26	15
1755	12	11	25	59	8	11	38	12	10	27	55	31	5	20	29	2
1756	30	8	58	38	9	0	0	24	10	3	32	37	6	29	12	3
1757	19	17	47	15	8	19	16	16	8	13	20	42	7	7	14	50
1758	9	2	35	51	8	8	32	8	6	23	8	47	7	15	17	38
1759	28	0	8	31	8	26	54	20	5	28	45	54	8	24	0	39
1760	16	8	57	8	8	16	10	12	4	8	34	0	9	2	3	26
1761	5	17	45	44	8	5	26	4	2	18	22	5	9	10	6	13
1762	24	15	18	24	8	23	48	16	1	23	59	11	10	18	49	14
1763	14	0	7	1	8	13	4	8	0	3	47	16	10	26	52	1
1764	2	8	55	36	8	2	20	0	10	13	35	21	11	4	54	48
1765	21	6	28	17	8	20	42	13	9	19	12	26	0	13	37	49
1766	10	15	16	53	8	9	58	5	7	29	0	31	0	21	40	37
1767	29	12	49	33	8	28	20	17	7	4	37	37	2	0	23	38
1768	17	21	38	9	8	17	36	9	5	14	25	42	2	8	26	25
1769	7	6	26	46	8	6	52	1	3	24	15	47	2	16	29	13
1770	26	3	59	26	8	25	14	13	2	29	50	53	3	25	12	14
1771	15	12	48	2	8	14	30	5	1	9	38	58	4	3	15	1
1772	3	21	36	39	8	3	45	57	11	19	27	3	4	11	17	48
1773	22	19	9	19	8	22	8	9	10	25	4	9	5	20	0	50
1774	12	3	57	55	8	11	24	1	9	4	52	14	5	28	3	37
1775	1	12	46	31	8	0	39	53	7	14	40	19	6	6	6	24
1776	19	10	19	12	8	19	2	5	6	20	17	25	7	14	49	25
1777	8	19	7	48	8	8	17	57	5	0	5	30	7	22	52	12
1778	27	16	40	28	8	26	40	9	4	5	42	36	9	1	35	13
1779	17	1	29	4	8	15	56	1	2	15	30	41	9	9	38	0
1780	5	10	17	40	8	5	11	53	0	25	18	46	9	17	40	47
1781	24	7	50	21	8	23	34	5	0	0	55	52	10	26	23	48
1782	13	16	38	57	8	12	49	58	10	10	43	57	11	4	26	35
1783	3	1	27	33	8	2	5	50	8	20	32	2	11	12	29	22
1784	20	23	0	13	8	20	28	3	9	26	9	2	0	21	12	23
1785	10	7	48	50	8	9	43	55	6	5	57	13	0	29	15	10
1786	29	5	21	30	8	28	6	7	5	11	34	19	2	7	58	12

Table II continued. New Style.

Year of Christ.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
1787	18	14	10	6	8	17	21	59	3	21	22	24	2	16	9	59
1788	6	22	58	42	8	6	37	51	2	1	10	29	2	24	3	46
1789	25	20	31	23	8	25	0	3	1	6	47	35	4	2	46	48
1790	15	5	19	59	8	14	15	55	11	16	35	40	4	10	49	35
1791	4	14	8	35	8	6	31	47	9	26	23	45	4	18	52	22
1792	22	11	41	15	8	21	53	59	9	2	0	52	5	27	35	24
1793	11	20	29	51	8	11	9	51	7	11	48	57	6	5	31	11
1794	30	18	2	32	8	29	32	3	6	17	26	4	7	14	21	13
1795	20	2	51	8	8	18	47	55	4	27	14	9	7	22	21	0
1796	8	11	39	44	8	8	3	47	3	7	2	11	8	0	26	47
1797	27	9	12	24	8	26	25	59	2	12	39	19	9	9	9	48
1798	16	18	1	1	8	15	41	51	0	22	27	25	9	17	12	35
1799	6	2	49	37	8	4	57	43	11	2	15	30	9	25	15	22
1800	25	0	22	17	8	23	19	55	10	7	52	36	11	3	58	24
1801	14	9	10	53	8	12	35	47	8	17	40	41	11	12	1	10
1802	3	17	59	29	8	1	51	39	6	27	28	46	11	20	3	57
1803	22	15	32	9	8	20	13	51	6	3	5	52	0	28	46	58
1804	11	0	20	45	8	9	29	43	4	12	53	57	1	6	49	15
1805	0	9	9	21	7	28	45	31	2	22	42	2	1	14	52	35
1806	19	6	42	1	8	17	7	43	1	28	19	8	2	23	35	36
1807	8	15	30	37	8	6	23	35	0	8	7	13	3	1	38	23
1808	26	13	3	17	8	24	45	47	11	13	44	19	4	10	21	21
1809	15	21	51	53	8	14	1	39	9	23	32	24	4	18	24	11
1810	5	6	40	29	8	3	17	31	8	3	20	29	4	26	26	58
1811	24	4	13	9	8	21	39	43	7	8	57	35	6	5	9	59
1812	12	13	1	45	8	10	55	35	5	18	45	40	6	13	12	46
1813	1	21	50	21	8	0	11	27	3	28	33	45	6	21	15	23
1814	20	19	23	1	8	18	38	39	3	4	10	51	7	29	58	24
1815	10	4	11	37	8	7	53	31	1	13	58	56	8	8	1	11
1816	28	1	44	17	8	26	15	43	0	19	36	2	9	16	44	12
1817	17	10	32	53	8	15	31	35	10	29	24	7	9	24	46	59
1818	6	19	21	29	8	4	47	27	9	9	12	12	10	2	49	46
1819	25	16	54	9	8	23	9	39	8	14	49	18	11	11	32	47
1820	14	1	42	45	8	12	25	31	6	24	37	23	11	19	35	34

Table II concluded. New Style.

Year of Christ.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
*1821	3	10	27	8	8	1	30	39	5	4	32	53	11	27	54	9
1822	22	7	59	45	8	19	52	50	4	10	10	4	1	6	17	11
1823	11	16	48	19	8	9	8	41	2	19	58	14	1	14	19	58
1824	29	14	20	56	8	27	30	51	1	25	35	24	2	23	3	0
1825	18	23	9	30	8	16	46	42	0	5	23	34	3	1	5	47
1826	8	7	58	4	8	6	2	34	10	15	11	44	3	9	8	35
1827	27	5	30	41	8	24	24	44	9	20	48	51	4	17	51	36
1828	15	14	19	16	8	13	40	35	8	0	37	4	4	25	54	24
1829	4	23	7	50	8	2	56	26	6	10	25	15	5	3	7	11
1830	23	20	40	27	8	21	18	37	5	16	2	25	6	12	40	13
1835	28	18	11	21	8	25	50	31	10	26	41	16	9	24	14	38
1840	3	2	58	17	8	1	16	6	3	11	31	5	0	5	8	49
1845	8	0	29	14	8	5	48	0	8	22	9	56	3	16	43	15
1850	12	22	0	11	8	10	19	54	2	2	48	47	6	28	17	40

* All the times of new Moon, &c. after 1820 are computed from more accurate data than those used for the other years.

Table III. Mean Anomalies, and Sun's mean Distance from the Node, for 13½ mean Lunations.

No.	Mean Lunations.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
1	29	12	44	3	0	29	6	19	0	25	49	0	1	0	40	14
2	59	1	28	6	1	28	12	39	1	21	38	1	2	1	20	28
3	88	14	12	9	2	27	18	58	2	17	27	1	3	2	0	42
4	118	2	56	12	3	26	25	17	3	13	16	2	4	2	40	56
5	147	15	40	15	4	25	31	37	4	9	5	2	5	3	21	10
6	177	4	24	18	5	24	37	56	5	4	54	3	6	4	1	24
7	206	17	8	21	6	23	44	15	6	0	43	3	7	4	41	38
8	236	5	52	24	7	22	50	35	6	26	32	3	8	5	21	52
9	265	18	36	27	8	21	56	54	7	22	21	4	9	6	2	6
10	295	7	20	30	9	21	3	14	8	18	10	4	10	6	42	20
11	324	20	4	33	10	20	9	33	9	13	59	5	11	7	22	34
12	354	8	48	36	11	19	15	52	10	9	48	5	0	8	2	47
13	383	21	32	40	0	18	22	12	11	5	37	6	1	8	44	1
* ½	14	18	22	2	0	14	33	10	6	12	54	30	0	15	20	7

Table IV. The Days of the Year, reckoned from the beginning of March

Days.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	January.	February.
1	1	32	62	93	123	154	185	215	246	276	307	338
2	2	33	63	94	124	155	186	216	247	277	308	339
3	3	34	64	95	125	156	187	217	248	278	309	340
4	4	35	65	96	126	157	188	218	249	279	310	341
5	5	36	66	97	127	158	189	219	250	280	311	342
6	6	37	67	98	128	159	190	220	251	281	312	343
7	7	38	68	99	129	160	191	221	252	282	313	344
8	8	39	69	100	130	161	192	222	253	283	314	345
9	9	40	70	101	131	162	193	223	254	284	315	346
10	10	41	71	102	132	163	194	224	255	285	316	347
11	11	42	72	103	133	164	195	225	256	286	317	348
12	12	43	73	104	134	165	196	226	257	287	318	349
13	13	44	74	105	135	166	197	227	258	288	319	350
14	14	45	75	106	136	167	198	228	259	289	320	351
15	15	46	76	107	137	168	199	229	260	290	321	352
16	16	47	77	108	138	169	200	230	261	291	322	353
17	17	48	78	109	139	170	201	231	262	292	323	354
18	18	49	79	110	140	171	202	232	263	293	324	355
19	19	50	80	111	141	172	203	233	264	294	325	356
20	20	51	81	112	142	173	204	234	265	295	326	357
21	21	52	82	113	143	174	205	235	266	296	327	358
22	22	53	83	114	144	175	206	236	267	297	328	359
23	23	54	84	115	145	176	207	237	268	298	329	360
24	24	55	85	116	146	177	208	238	269	299	330	361
25	25	56	86	117	147	178	209	239	270	300	331	362
26	26	57	87	118	148	179	210	240	271	301	332	363
27	27	58	88	119	149	180	211	241	272	302	333	364
28	28	59	89	120	150	181	212	242	273	303	334	365
29	29	60	90	121	151	182	213	243	274	304	335	366
30	30	61	91	122	152	183	214	244	275	305	336	
31	31		92		153	184		245		306	337	

Table V. Mean Lunations from 1 *to* 100000.

Lunat.	Days. Decimal parts.	D.	H.	M.	S.	‴	⁗
1	29.530590851080	= 29	12	44	3	2	58
2	59.061181702160	59	1	28	6	5	57
3	88.591772553240	88	14	12	9	8	55
4	118.122363404320	118	2	56	12	11	53
5	147.652954255401	147	15	40	15	14	52
6	177.183545106481	177	4	24	18	17	50
7	206.714135957561	206	17	8	21	20	48
8	236.244726808641	236	5	52	24	23	47
9	265.775317659722	265	18	36	27	26	45
10	295.30590851080	295	7	20	30	29	43
20	590.61181702160	590	14	41	0	59	26
30	885.91772553240	885	22	1	31	29	10
40	1181.22363404320	1181	5	22	1	58	53
50	1476.52954255401	1476	12	42	32	28	36
60	1771.83545106481	1771	20	3	2	58	19
70	2067.14135957561	2067	3	23	33	28	2
80	2362.44726808641	2362	10	44	3	57	46
90	2657.75317659722	2657	18	4	34	27	29
100	2953.0590851080	2953	1	25	4	57	12
200	5906.1181702160	5906	2	50	9	54	24
300	8859.1772553240	8859	4	15	14	51	36
400	11812.2363404320	11812	5	40	19	48	48
500	14765.2954255401	14765	7	5	24	46	0
600	17718.3545106481	17718	8	30	29	43	12
700	20671.4135957561	20671	9	55	34	40	24
800	23624.4726808641	23624	11	20	39	37	36
900	26577.5317659722	26577	12	45	44	34	48
1000	29530.590851080	29530	14	10	49	32	0
2000	59061.181702160	59061	4	21	39	4	0
3000	88591.772553140	88591	18	32	28	36	0
4000	118122.363404320	118122	8	43	18	8	0
5000	147652.954255401	147652	22	54	7	40	0
6000	177183.545106481	177183	13	4	57	12	0
7000	206714.135957561	206714	3	15	46	44	0
8000	236244.726801641	236244	17	26	36	16	0
9000	265775.317659722	265775	7	37	25	48	0
10000	295305.90851080	295305	21	48	15	20	0
20000	590611.87102160	590611	19	36	30	40	0
30000	885917.72553240	885917	17	24	46	0	0
40000	1181223.63404320	1181223	15	13	1	20	0
50000	1476529.54255401	1476529	13	1	16	40	0
60000	1771835.45106481	1771835	10	49	32	0	0
70000	2067141.35957561	2067141	8	37	47	20	0
80000	2362447.26808641	2362147	6	25	2	40	0
90000	2657753.17659722	2657753	4	14	18	0	0
100000	2953959.0851080	2953059	2	2	33	20	0

Table VI. The first mean New Moon, with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Ascending Node, next after complete Centuries of Julian years.

Lunations	Julian years.	First New Moon.				Sun's mean Anomaly.			Moon's mean Anomaly.			Sun from Node.		
		D.	H.	M.	S.	s	°	'	s	°	'	s	°	'
1237	100	1	8	10	52	0	3	21	8	13	22	4	19	27
2474	200	8	16	21	44	0	6	42	5	0	44	9	8	55
3711	300	13	0	32	37	0	10	3	1	16	6	1	28	22
4948	400	17	8	43	29	0	13	24	10	1	28	6	17	19
6185	500	21	16	54	21	0	16	46	6	16	50	11	7	16
7422	600	26	1	5	14	0	20	7	3	2	12	3	26	11
8658	700	0	20	32	3	11	24	22	10	21	45	7	15	31
9895	800	5	4	42	55	11	27	43	7	7	7	0	4	58
11132	900	9	12	53	47	0	1	4	3	22	29	4	21	25
12369	1000	13	21	4	40	0	4	25	0	7	51	9	13	53
13606	1100	18	5	15	32	0	7	46	8	23	13	2	3	20
14843	1200	22	13	26	24	0	11	7	5	8	35	6	22	17
16080	1300	26	21	37	16	0	14	28	1	23	57	11	12	15
17316	1400	1	17	4	6	11	18	49	9	13	30	3	1	2
18553	1500	6	1	14	58	11	22	4	5	28	52	7	20	29
19790	1600	10	9	25	50	11	25	25	2	14	14	0	9	56
21027	1700	14	17	36	42	11	28	46	10	29	36	4	29	23
22264	1800	19	1	47	35	0	2	8	7	14	58	9	18	51
23501	1900	23	9	58	27	0	5	29	4	0	20	2	8	18
24738	2000	27	18	9	19	0	8	50	0	15	42	6	27	45
25974	2100	2	13	36	8	11	13	5	8	5	15	10	16	32
27211	2200	6	21	47	1	11	16	26	4	20	37	3	6	0
28448	2300	11	5	57	53	11	19	47	1	5	59	7	25	27
29685	2400	15	14	8	45	11	23	8	9	21	21	0	14	54
30922	2500	19	22	19	38	11	26	29	6	6	43	5	4	22
32159	2600	24	6	30	30	11	29	50	2	22	4	9	23	49
33396	2700	28	14	41	22	0	3	11	11	7	26	2	13	16
34632	2800	3	10	8	11	11	7	26	6	26	59	6	2	3
35869	2900	7	18	19	3	11	10	47	3	12	21	10	21	30
37106	3000	12	2	29	56	11	14	8	11	27	43	3	10	58
38343	3100	16	10	40	48	11	17	30	8	13	5	8	0	25
39580	3200	20	18	51	40	11	20	51	4	28	27	0	19	52

Table VI concluded.

Lunation.	Julian years	First New Moon.				Sun's mean Anomaly.			Moon's mean Anomaly.			Sun's mean Dist. from Node.		
		D.	H.	M.	S.	s	°	′	s	°	′	s	°	′
40817	3300	25	3	2	23	11	24	12	1	13	49	5	9	20
42054	3400	29	11	13	25	11	27	33	9	29	11	9	28	47
43290	3500	1	6	10	14	11	1	18	5	18	44	1	17	34
44527	3600	8	14	51	6	11	5	9	2	4	6	6	7	1
45761	3700	12	23	1	59	11	8	30	10	19	28	10	26	29
47001	3800	17	7	12	51	11	11	51	7	4	50	3	15	56
48238	3900	21	15	23	43	11	15	12	3	20	12	8	5	23
49475	4000	25	23	31	35	11	18	33	0	5	34	0	24	50
50711	4100	0	19	1	27	10	22	48	7	25	7	4	13	37
51948	4200	5	3	12	17	10	26	9	4	10	29	9	3	5
53185	4300	6	11	23	9	10	29	31	0	25	51	1	22	32
54122	4400	13	19	34	1	11	2	52	9	11	13	6	11	59
55659	4500	18	3	44	54	11	6	13	5	26	35	11	1	27
56896	4600	22	11	55	46	11	9	34	2	11	57	3	20	54
58133	4700	26	20	6	38	11	12	55	10	27	19	8	10	21
59369	4800	1	15	33	27	10	17	9	6	16	52	11	29	8
60606	4900	5	23	44	20	10	20	31	3	2	14	4	18	36
61843	5000	10	7	55	12	10	23	52	11	17	36	9	8	3
63080	5100	14	16	6	4	10	27	13	8	2	58	1	27	30
64317	5200	19	0	16	56	11	0	34	4	18	20	6	16	57
65554	5300	23	8	27	49	11	3	55	1	3	42	11	6	25
66791	5400	27	16	38	41	11	7	16	9	19	4	2	25	52
68028	5500	2	12	5	30	10	11	31	5	8	37	7	14	39
69265	5600	6	20	16	22	10	14	52	1	23	59	0	4	6
70502	5700	11	4	27	15	10	18	14	10	9	21	4	23	34
71739	5800	15	12	38	7	10	21	35	6	24	43	9	13	1
72976	5900	19	20	48	59	10	24	56	3	10	5	2	2	28
74212	6000	24	4	59	52	10	28	17	11	25	27	6	21	56

If Dr. Pound's mean Lunation (which we have kept by in making these tables) be added 74212 times to itself, the sum will amount to 6000 Julian years 24 days 4 hours 59 minutes 51 seconds 40 thirds; agreeing with the first part of the last line of this table, within half a second.

Table VII. The annual, or first Equation of the mean to the true Syzygy.

Argument Sun's mean Anomaly

Subtract

Degrees	0 Signs			1 Sign			2 Signs			3 Signs			4 Signs			5 Signs			Degrees
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	
0	0	0	0	2	3	12	3	35	0	4	10	53	3	39	30	2	7	45	30
1	0	4	18	2	6	55	3	37	10	4	10	57	3	37	19	2	3	55	29
2	0	8	35	2	10	35	3	39	18	4	10	55	3	35	6	2	0	1	28
3	0	12	51	2	14	14	3	41	23	4	10	49	3	32	50	1	56	5	27
4	0	17	8	2	17	52	3	43	26	4	10	39	3	30	50	1	52	6	26
5	0	21	24	2	21	27	3	45	25	4	10	24	3	28	5	1	48	4	25
6	0	25	39	2	25	9	3	47	19	4	10	4	3	25	55	1	41	1	21
7	0	28	55	2	28	29	3	49	7	4	9	39	3	23	0	1	39	56	23
8	0	34	11	2	31	57	3	50	50	4	9	10	3	20	20	1	35	49	22
9	0	38	26	2	35	22	3	52	29	4	8	37	3	17	35	1	31	41	21
10	0	42	39	2	38	44	3	54	4	4	7	59	3	14	49	1	27	31	20
11	0	46	52	2	42	3	3	55	35	4	7	16	3	11	59	1	23	19	19
12	0	51	4	2	45	18	3	57	2	4	6	29	3	9	6	1	19	5	18
13	0	55	17	2	48	30	3	58	27	3	5	57	3	6	10	1	14	49	17
14	0	59	27	2	51	40	3	59	49	4	4	41	3	3	10	1	10	33	16
15	1	3	36	2	54	48	3	1	7	4	3	40	3	0	7	1	6	15	15
16	1	7	45	2	57	59	4	2	[illegible]	4	2	35	2	57	0	1	1	56	14
17	1	11	52	3	0	54	4	3	23	4	1	26	2	53	49	0	57	36	13
18	1	16	0	3	3	51	4	4	22	4	0	12	2	50	36	0	53	15	12
19	1	20	6	3	6	45	4	5	18	3	58	52	2	47	18	0	48	52	11
20	1	24	10	3	9	36	4	6	10	3	57	27	2	43	57	0	44	28	10
21	1	28	12	3	12	24	4	6	58	3	55	59	2	40	33	0	40	2	9
22	1	32	12	3	15	9	4	7	41	3	54	26	2	37	6	0	35	36	8
23	1	36	10	3	17	51	4	8	21	3	52	49	2	33	35	0	31	10	7
24	1	40	6	3	20	30	4	8	57	3	51	9	2	30	2	0	26	44	6
25	1	44	1	3	23	5	4	9	29	3	49	26	2	26	26	0	22	17	5
26	1	47	54	3	25	36	4	9	55	3	47	38	2	22	47	0	17	50	4
27	1	51	46	3	28	3	4	10	16	3	45	44	2	19	5	0	13	23	3
28	1	55	37	3	30	26	4	10	33	3	43	45	2	15	20	0	8	56	2
29	1	59	26	3	32	45	4	10	45	3	41	40	2	11	35	0	4	29	1
30	2	3	12	3	35	0	4	10	53	3	39	30	2	7	45	0	0	0	0
Deg.	11 Signs			10 Signs			9 Signs			8 Signs			7 Signs			6 Signs			Deg.

Add

Table VIII. Equation of the Moon's mean Anomaly.

Degrees	0 Signs °	′	″	1 Sign °	′	″	2 Signs °	′	″	3 Signs °	′	″	4 Signs °	′	″	5 Signs °	′	″	Degrees
	Argument. Sun's mean Anomaly. Subtract																		
0	0	0	0	0	46	45	1	21	32	1	35	1	1	23	4	0	48	19	30
1	0	1	37	0	48	10	1	22	21	1	35	2	1	22	14	0	46	51	29
2	0	3	13	0	49	34	1	23	10	1	35	1	1	21	24	0	45	23	28
3	0	4	52	0	50	53	1	23	57	1	35	0	1	20	32	0	43	54	27
4	0	6	28	0	52	19	1	24	41	1	34	57	1	19	38	0	42	24	26
5	0	8	6	0	53	40	1	25	24	1	34	50	1	18	42	0	40	53	25
6	0	9	42	0	55	0	1	26	6	1	34	43	1	17	45	0	39	21	24
7	0	11	20	0	56	21	1	26	48	1	34	33	1	16	48	0	37	49	23
8	0	12	56	0	57	38	1	27	28	1	34	22	1	15	47	0	36	15	22
9	0	14	33	0	58	56	1	28	6	1	34	9	1	14	44	0	34	40	21
10	0	16	10	1	0	13	1	28	43	1	33	53	1	13	41	0	33	5	20
11	0	17	47	1	1	29	1	29	17	1	33	37	1	12	37	0	31	31	19
12	0	19	23	1	2	43	1	29	51	1	33	20	1	11	33	0	29	54	18
13	0	20	59	1	3	56	1	30	22	1	33	0	1	10	26	0	28	18	17
14	0	22	35	1	5	8	1	30	50	1	32	38	1	9	17	0	26	40	16
15	0	24	10	1	6	18	1	31	19	1	32	14	1	8	8	0	25	3	15
16	0	25	45	1	7	27	1	31	45	1	31	50	1	6	58	0	23	23	14
17	0	27	19	1	8	36	1	32	12	1	31	23	1	5	46	0	21	45	13
18	0	28	52	1	9	42	1	32	34	1	30	55	1	4	32	0	20	7	12
19	0	30	25	1	10	49	1	32	57	1	30	25	1	3	19	0	18	28	11
20	0	31	57	1	11	54	1	33	17	1	29	54	1	2	1	0	16	48	10
21	0	33	29	1	12	58	1	33	36	1	29	20	1	0	45	0	15	8	9
22	0	35	2	1	14	1	1	33	52	1	28	45	0	59	26	0	13	28	8
23	0	36	32	1	15	1	1	34	6	1	28	9	0	58	7	0	11	48	7
24	0	38	1	1	16	0	1	34	18	1	27	30	0	56	45	0	10	7	6
25	0	39	29	1	16	59	1	34	30	1	26	50	0	55	23	0	8	20	5
26	0	40	59	1	17	57	1	34	40	1	26	27	0	54	1	0	6	44	4
27	0	42	26	1	18	52	1	34	48	1	25	50	0	52	37	0	5	3	3
28	0	43	54	1	19	47	1	34	54	1	24	39	0	51	12	0	3	21	2
29	0	45	19	1	20	40	1	34	58	1	23	52	0	49	45	0	1	40	1
30	0	47	45	1	21	32	1	35	1	1	23	4	0	48	19	0	0	0	0
Deg.	11 Signs			10 Signs			9 Signs			8 Signs			7 Signs			6 Signs			Deg.
	Add																		

Table IX. The second Equation of the Mean to the True Syzygy.

Degrees	0 Signs. H.	M.	S.	1 Sign. H.	M.	S.	2 Signs. H.	M.	S.	3 Signs. H.	M.	S.	4 Signs. H.	M.	S.	5 Signs. H.	M.	S.	Degrees
	Argument. Sun's equated Anomaly. Add																		
0	0	0	0	5	12	48	8	47	8	9	46	44	8	8	59	4	34	33	30
1	0	10	58	5	21	56	8	51	45	9	45	3	8	3	12	4	26	1	29
2	0	21	56	5	30	57	8	56	10	9	45	12	7	57	28	4	17	25	28
3	0	32	54	5	39	51	9	0	25	9	44	11	7	51	33	4	8	17	27
4	0	43	52	5	48	37	9	4	31	9	42	59	7	45	16	4	0	7	26
5	0	54	50	5	57	17	9	8	25	9	41	36	7	39	16	3	51	23	25
6	1	5	48	6	5	51	9	12	9	9	40	3	7	33	36	3	42	32	24
7	1	16	46	6	14	19	9	15	43	9	38	19	7	27	22	3	33	38	23
8	1	27	41	6	22	41	9	19	5	9	36	21	7	21	2	3	24	12	22
9	1	38	40	6	30	57	9	22	11	9	34	18	7	14	30	3	15	11	21
10	1	49	33	6	39	1	9	23	12	9	32	1	7	7	50	3	6	45	20
11	2	0	23	6	47	0	9	27	51	9	29	33	7	1	2	2	57	45	19
12	2	11	10	6	54	46	9	30	32	9	26	51	6	54	8	2	48	39	18
13	2	21	54	7	2	24	9	32	58	9	24	4	6	47	9	2	39	31	17
14	2	32	34	7	9	52	9	35	12	9	21	5	6	10	6	2	30	28	16
15	2	43	9	7	17	9	9	37	14	9	17	51	6	32	56	2	21	19	15
16	2	53	38	7	24	19	9	39	8	9	14	48	6	25	40	2	12	8	14
17	3	4	3	7	31	18	9	40	51	9	10	51	6	18	18	2	2	53	13
18	3	14	24	7	38	9	9	42	21	9	7	9	6	10	49	1	53	36	12
19	3	24	42	7	44	51	9	43	42	9	3	13	6	3	16	1	44	16	11
20	3	34	58	7	51	21	9	44	53	8	59	6	5	55	38	1	34	54	10
21	3	45	11	7	57	45	9	45	52	8	54	50	5	47	54	1	25	31	9
22	3	55	21	8	3	56	9	46	38	8	50	24	5	40	4	1	16	7	8
23	4	5	26	8	9	57	9	47	13	8	45	48	5	32	9	1	6	41	7
24	4	25	26	8	15	46	9	47	36	8	41	2	5	24	9	0	57	13	6
25	4	25	20	8	21	24	9	47	49	8	36	6	5	16	5	0	47	44	5
26	4	35	6	8	26	53	9	47	51	8	31	0	5	7	56	0	38	13	4
27	4	44	42	8	32	11	9	47	46	8	25	44	4	59	42	0	28	41	3
28	4	54	11	8	37	19	9	47	33	8	20	18	4	51	15	0	19	8	2
29	5	3	33	8	42	18	9	47	14	8	14	33	4	43	2	0	9	34	1
30	5	12	48	8	47	8	9	46	41	8	8	59	4	34	33	0	0	0	0
Deg.	11 Signs.			10 Signs.			9 Signs.			8 Signs.			7 Signs.			6 Signs.			Deg.
	Subtract																		

Table X. The Third Equation of the mean to the true Syzygy.

Argument Sun's Anom.—Moon's Anom.

Degrees.	Signs. 0 Sub. 6 Add M.	S.	Signs. 1 Sub. 7 Add M.	S.	Signs. 2 Sub. 8 Add M.	S.	Degrees.
0	0	0	2	22	4	12	30
1	0	5	2	26	4	15	29
2	0	10	2	30	4	18	28
3	0	15	2	34	4	21	27
4	0	20	2	38	4	24	26
5	0	25	2	42	4	27	25
6	0	30	2	46	4	30	24
7	0	35	2	50	4	32	23
8	0	40	2	54	4	34	22
9	0	45	2	58	4	36	21
10	0	50	3	2	4	38	20
11	0	55	3	6	4	40	19
12	1	0	3	10	4	42	18
13	1	5	3	14	4	44	17
14	1	10	3	18	4	46	16
15	1	15	3	22	4	48	15
16	1	20	3	26	4	50	14
17	1	25	3	30	4	51	13
18	1	30	3	34	4	52	12
19	1	35	3	38	4	53	11
20	1	40	3	42	4	54	10
21	1	45	3	45	4	55	9
22	1	49	3	48	4	56	8
23	1	52	3	51	4	57	7
24	1	56	3	54	4	57	6
25	2	0	3	57	4	57	5
26	2	4	4	0	4	58	4
27	2	9	4	3	4	58	3
28	2	13	4	6	4	58	2
29	2	18	4	9	4	58	1
30	2	22	4	12	4	58	0
Degrees.	Signs. 5 Sub. 11 Add		Signs. 4 Sub. 10 Add		Signs. 3 Sub. 9 Add		Degrees.

Table XI. The Fourth Equation of the mean to the true Syzygy.

Argument. Sun's mean Distance from the Node

Add

Degrees.	0 } 6 } Sig. M.	S.	1 } 7 } Sig. M.	S.	2 } 8 } Sig. M.	S.	Degrees.
0	0	0	1	22	1	22	30
1	0	4	1	23	1	21	29
2	0	7	1	24	1	20	28
3	0	10	1	25	1	18	27
4	0	13	1	26	1	16	26
5	0	16	1	27	1	14	25
6	0	20	1	28	1	12	24
7	0	23	1	29	1	10	23
8	0	26	1	30	1	8	22
9	0	29	1	31	1	6	21
10	0	32	1	32	1	3	20
11	0	35	1	33	1	0	19
12	0	38	1	33	0	57	18
13	0	41	1	34	0	54	17
14	0	44	1	34	0	51	16
15	0	47	1	34	0	49	15
16	0	50	1	34	0	45	14
17	0	52	1	34	0	41	13
18	0	54	1	34	0	37	12
19	0	57	1	33	0	34	11
20	1	0	1	33	0	31	10
21	1	2	1	32	0	28	9
22	1	5	1	31	0	25	8
23	1	8	1	30	0	22	7
24	1	10	1	29	0	19	6
25	1	12	1	28	0	16	5
26	1	14	1	27	0	13	4
27	1	16	1	26	0	10	3
28	1	18	1	25	0	6	2
29	1	20	1	24	0	3	1
30	1	22	1	22	0	0	0
Deg.	5 } 11 } Sig.		4 } 10 } Sig.		3 } 9 } Sig.		Deg.

Subtract

Table XII. The Sun's mean Longitude, Motion, and Anomaly.

Years beginning.	Sun's mean Longitude. s.	°	′	″	Sun's mean Anomaly. s.	°	′	″
O. S. 1	9	7	53	10	6	28	48	0
201	9	9	23	50	6	26	57	0
301	9	10	9	10	6	26	1	0
401	9	10	54	30	6	25	5	0
501	9	11	39	50	6	24	9	0
1001	9	15	26	30	6	19	32	0
1101	9	16	11	50	6	18	36	0
1201	9	16	57	10	6	17	40	0
1301	9	17	42	30	6	16	44	0
1401	9	18	27	50	6	15	49	0
1501	9	19	13	10	6	14	53	0
1601	9	19	58	30	6	13	57	0
1701	9	20	43	50	6	13	1	0
1801	9	21	29	10	6	12	6	0
N. S. 1797	9	10	37	33	6	1	8	17
1798	9	10	23	13	6	0	52	51
1799	9	10	8	54	6	0	37	26
1800	9	9	54	35	6	0	22	1
1801	9	9	40	16	6	0	6	36
1802	9	9	25	56	5	29	51	10
1803	9	9	11	37	5	29	35	45
1804	9	9	56	26	6	0	19	28
1805	9	9	42	6	6	0	4	2
1806	9	9	27	48	5	29	48	38
1807	9	9	13	29	5	29	33	13
1808	9	9	58	17	6	0	16	48
1809	9	9	43	57	6	0	1	31
1810	9	9	29	37	5	29	45	57
1811	9	9	15	17	5	29	30	32
1812	9	10	0	5	6	0	14	15
1813	9	9	45	45	5	29	58	49
1814	9	9	31	25	5	29	43	26
1815	9	9	17	5	5	29	27	58
1816	9	10	1	53	6	0	11	41
1817	9	9	47	33	5	29	56	15
1818	9	9	33	13	5	29	40	50
1819	9	9	18	53	5	29	25	24
1820	9	10	3	41	6	0	9	7
1821	9	9	49	22	5	29	55	42

Years complete.	Sun's mean Motion. s.	°	′	″	Sun's mean Anomaly. s.	°	′
1	11	29	45	40	11	29	45
2	11	29	31	21	11	29	29
3	11	29	17	20	11	29	14
4	0	0	1	50	11	29	58
5	11	29	47	31	11	29	42
6	11	29	33	11	11	29	27
7	11	29	18	52	11	29	11
8	0	0	3	41	11	29	55
9	11	29	49	21	11	29	40
10	11	29	35	2	11	29	24
11	11	29	20	42	11	29	9
12	0	0	5	31	11	29	53
13	11	29	51	12	11	29	37
14	11	29	36	52	11	29	22
15	11	29	22	33	11	29	7
16	0	0	7	22	11	29	50
17	11	29	53	2	11	29	35
18	11	29	38	43	11	29	20
19	11	29	24	23	11	29	4
20	0	0	9	12	11	29	48
40	0	0	18	24	11	29	37
60	0	0	27	36	11	29	26
80	0	0	36	48	11	29	15
100	0	0	46	0	11	29	4
200	0	1	32	0	11	28	8
300	0	2	18	0	11	27	12
400	0	3	4	0	11	26	16
500	0	3	50	0	11	25	21
600	0	4	32	0	11	24	25
700	0	5	17	20	11	23	29
800	0	6	2	40	11	22	33
900	0	6	48	0	11	21	37
1000	0	7	40	0	11	20	41
2000	0	15	20	0	11	11	22
3000	0	22	40	0	11	2	3
4000	1	0	13	20	10	22	44
5000	1	7	46	40	10	13	25
6000	1	15	20	0	10	4	6

Table XII continued.

Months.	Sun's mean Motion.				Sun's mean Anomaly.		
	s.	°	′	″	s.	°	′
January	0	0	0	0	0	0	8
February	1	0	33	18	1	0	33
March	1	28	9	11	1	28	9
April	2	28	42	30	2	28	42
May	3	28	16	40	3	28	17
June	4	28	49	58	4	28	50
July	5	28	24	8	5	28	24
August	6	28	57	26	6	28	57
September	7	29	30	44	7	29	30
October	8	29	4	54	8	29	4
November	9	29	38	12	9	29	37
December	10	29	12	22	10	29	11

Days.	Sun's mean Motion and Anomaly.				Days.	Sun's mean Motion and Anomaly.			
	s.	°	′	″		s.	°	′	″
1	0	0	59	8	17	0	16	45	22
2	0	1	58	17	18	0	17	44	30
3	0	2	57	25	19	0	18	43	38
4	0	3	56	33	20	0	19	42	47
5	0	4	55	42	21	0	20	41	55
6	0	5	54	50	22	0	21	41	3
7	0	6	53	58	23	0	22	40	12
8	0	7	53	7	24	0	23	39	20
9	0	8	52	15	25	0	24	38	28
10	0	9	51	23	26	0	25	37	37
11	0	10	50	32	27	0	26	36	45
12	0	11	49	40	28	0	27	35	53
13	0	12	48	48	29	0	28	35	2
14	0	13	47	57	30	0	29	34	10
15	0	14	47	5	31	1	30	33	18
16	0	15	46	13					

Table XII concluded.

	Sun's mean Motion and Anamoly.	Sun's m Dist from Node		Sun's mean Motion and Anomaly	Sun's m Dist from Node
H. M. S.	° ′ ″ ′ ″ ‴ ″ ‴ ′	° ′ ″ ′ ″ ″ ″ ‴ ⁗	H M. S.	° ′ ″ ′ ″ ″ ″ ″ ′	° ′ ′ ′ ″ ′
1	0 2 28	0 2 36	31	1 16 23	1 20 30
2	0 4 56	0 5 12	32	1 18 51	1 23 6
3	0 7 24	0 7 48	33	1 21 19	1 25 42
4	0 9 51	0 10 23	34	1 23 47	1 28 18
5	0 12 19	0 12 59	35	1 26 15	1 30 54
6	0 14 47	0 15 35	36	1 28 42	1 33 29
7	0 17 15	0 18 11	37	1 31 10	1 36 5
8	0 19 43	0 20 47	38	1 33 38	1 38 40
9	0 22 11	0 23 23	39	1 36 6	1 41 16
10	0 24 38	0 25 58	40	1 38 34	1 43 52
11	0 27 6	0 28 34	41	1 41 2	1 46 28
12	0 29 34	0 31 10	42	1 43 30	1 49 4
13	0 32 2	0 33 45	43	1 45 57	1 51 39
14	0 34 30	0 36 21	44	1 48 25	1 54 15
15	0 36 58	0 38 57	45	1 50 53	1 55 51
16	0 39 26	0 41 33	46	1 53 21	1 59 27
17	0 41 53	0 44 8	47	1 55 49	2 2 3
18	0 44 21	0 46 44	48	1 58 17	2 4 39
19	0 46 49	0 49 20	49	2 0 44	2 7 13
20	0 49 17	0 51 56	50	2 3 12	2 9 50
21	0 51 45	0 54 32	51	2 5 40	2 12 25
22	0 54 13	0 57 8	52	2 8 8	2 15 2
23	0 56 40	0 59 43	53	2 10 36	2 17 38
24	0 59 8	1 2 19	54	2 13 4	2 20 14
25	1 1 36	1 4 55	55	2 15 32	2 22 50
26	1 4 4	1 7 31	56	2 17 59	2 25 26
27	1 6 32	1 10 7	57	2 20 27	2 28 2
28	1 9 0	1 12 43	58	2 22 55	2 30 38
29	1 11 28	1 15 19	59	2 25 23	2 33 14
30	1 13 55	1 17 55	60	2 27 51	2 35 50

. In leap-years, after February, add one day and one day's motion.

Table XIII. Equation of the Sun's Centre, or the Difference between his Mean and True Place.

Argument. Sun's mean Anomaly. Subtract																			
Degrees.	0 Signs.			1 Sign.			2 Signs.			3 Signs.			4 Signs.			5 Signs.			Degrees.
	°	′	″	°	′	″	°	′	″	°	′	″	°	′	″	°	′	″	
0	0	0	0	0	56	47	1	39	6	1	55	37	1	41	12	0	58	38	30
1	0	1	59	0	58	30	1	40	7	1	55	39	1	40	12	0	57	7	29
2	0	3	57	1	0	12	1	41	6	1	55	38	1	39	10	0	55	19	28
3	0	5	56	1	1	53	1	42	3	1	55	36	1	38	6	0	53	30	27
4	0	7	54	1	3	33	1	42	59	1	55	31	1	37	0	0	51	40	26
5	0	9	52	1	5	12	1	43	52	1	55	24	1	35	52	0	49	49	25
6	0	11	50	1	6	50	1	44	44	1	55	15	1	34	43	0	47	57	24
7	0	13	48	1	8	27	1	45	34	1	55	3	1	33	32	0	46	5	23
8	0	15	46	1	10	2	1	46	22	1	54	50	1	32	19	0	44	11	22
9	0	17	43	1	11	36	1	47	8	1	54	35	1	31	4	0	42	16	21
10	0	19	40	1	13	9	1	47	53	1	54	17	1	29	47	0	40	21	20
11	0	21	37	1	14	41	1	48	35	1	53	57	1	28	29	0	38	25	19
12	0	23	33	1	16	11	1	49	15	1	53	36	1	27	9	0	36	28	18
13	0	25	29	1	17	40	1	49	54	1	53	12	1	25	48	0	34	30	17
14	0	27	25	1	19	8	1	50	30	1	52	46	1	24	25	0	32	32	16
15	0	29	20	1	20	34	1	51	5	1	52	18	1	23	0	0	30	33	15
16	0	31	15	1	21	59	1	51	37	1	51	48	1	21	34	0	28	33	14
17	0	33	9	1	23	22	1	52	8	1	51	15	1	20	6	0	26	33	13
18	0	35	2	1	24	44	1	52	36	1	50	41	1	18	36	0	24	33	12
19	0	36	55	1	26	5	1	53	3	1	50	5	1	17	5	0	22	32	11
20	0	38	47	1	27	24	1	53	27	1	49	26	1	15	33	0	20	30	10
21	0	40	39	1	28	41	1	53	50	1	48	46	1	13	59	0	18	28	9
22	0	42	30	1	29	57	1	54	10	1	48	3	1	12	24	0	16	26	8
23	0	44	20	1	31	11	1	54	28	1	47	19	1	10	47	0	14	24	7
24	0	46	9	1	32	25	1	54	44	1	46	32	1	9	9	0	12	21	6
25	0	47	57	1	33	35	1	54	58	1	45	44	1	7	29	0	10	18	5
26	0	49	45	1	34	45	1	55	10	1	44	53	1	5	49	0	8	14	4
27	0	51	32	1	35	53	1	55	20	1	44	1	1	4	7	0	6	11	3
28	0	53	18	1	36	59	1	55	28	1	43	7	1	2	24	0	4	7	2
29	0	55	3	1	38	3	1	55	34	1	42	10	1	0	39	0	2	4	1
30	0	56	47	1	39	6	1	55	37	1	41	12	0	58	53	0	0	0	0
Deg.	11 Signs.			10 Signs.			9 Signs.			8 Signs.			7 Signs.			6 Signs.			Deg.
Add																			

* *Table XIV. The Sun's Declination.*

Degrees.	Signs. 0 N. 6 S.		Signs. 1 N. 7 S.		Signs. 2 N. 8 S.		Degrees.
	°	′	°	′	°	′	
0	0	0	11	30	20	11	30
1	0	24	11	51	20	24	29
2	0	48	12	11	20	36	28
3	1	12	12	32	20	48	27
4	1	36	12	53	20	59	26
5	1	59	13	13	21	10	25
6	2	23	13	33	21	21	24
7	2	47	13	53	21	31	23
8	3	11	14	12	21	41	22
9	3	34	14	31	21	50	21
10	3	58	14	50	21	59	20
11	4	22	15	9	22	8	19
12	4	45	15	28	22	16	18
13	5	9	15	46	22	24	17
14	5	32	16	4	22	31	16
15	5	55	16	22	22	38	15
16	6	18	16	39	22	45	14
17	6	41	16	57	22	51	13
18	7	4	17	14	22	56	12
19	7	27	17	30	23	2	11
20	7	50	17	46	23	6	10
21	8	13	18	2	23	11	9
22	8	35	18	18	23	14	8
23	9	57	18	33	23	18	7
24	9	20	18	48	23	21	6
25	9	42	19	3	23	21	5
26	10	4	19	17	23	25	4
27	10	25	19	31	23	27	3
28	10	47	19	45	23	28	2
29	11	8	19	58	23	29	1
30	11	30	20	11	23	29	0
Degrees.	Signs. 11 S. 5 N.		Signs. 10 S. 4 N.		Signs. 9 S. 3 N.		Degrees.

Argument. Sun's true Place.

Table XV. Equation of the Sun's mean Distance from the Node.

Argument. Sun's mean Anomaly.													
Subtract													
Degrees.	0 Signs.		1 Signs.		2 Signs.		3 Signs.		4 Signs.		5 Signs.		Degrees.
	°	′	°	′	°	′	°	′	°	′	°	′	
0	0	0	1	2	1	47	2	5	1	50	1	4	30
1	0	2	1	4	1	48	2	5	1	48	1	2	29
2	0	4	1	6	1	49	2	5	1	47	1	0	28
3	0	6	1	8	1	50	2	5	1	46	0	58	27
4	0	9	1	10	1	51	2	5	1	45	0	56	26
5	0	11	1	12	1	52	2	5	1	44	0	54	25
6	0	13	1	14	1	53	2	5	1	43	0	52	24
7	0	15	1	16	1	54	2	4	1	41	0	50	23
8	0	17	1	17	1	55	2	4	1	40	0	48	22
9	0	19	1	18	1	56	2	4	1	39	0	46	21
10	0	21	1	19	1	57	2	4	1	37	0	44	20
11	0	23	1	21	1	58	2	3	1	36	0	42	19
12	0	25	1	22	1	58	2	3	1	34	0	40	18
13	0	28	1	24	1	59	2	3	1	33	0	37	17
14	0	30	1	26	2	0	2	2	1	31	0	35	16
15	0	32	1	27	2	0	2	2	1	30	0	33	15
16	0	34	1	28	2	1	2	1	1	28	0	31	14
17	0	36	1	30	2	1	2	1	1	27	0	20	13
18	0	38	1	31	2	2	2	0	1	25	0	27	12
19	0	40	1	34	2	2	2	0	1	24	0	24	11
20	0	42	1	35	2	3	1	59	1	23	0	22	10
21	0	44	1	36	2	3	1	59	1	21	0	20	9
22	0	46	1	37	2	4	1	58	1	19	0	18	8
23	0	48	1	39	2	4	1	57	1	17	0	16	7
24	0	50	1	40	2	4	1	56	1	15	0	13	6
25	0	52	1	41	2	4	1	55	1	13	0	11	5
26	0	54	1	43	2	5	1	54	1	11	0	9	4
27	0	56	1	44	2	5	1	53	1	9	0	7	3
28	0	58	1	45	2	5	1	52	1	8	0	5	2
29	1	0	1	46	2	5	1	51	1	6	0	3	1
30	1	2	1	47	2	5	1	50	1	4	0	0	0
Deg.	11 Signs.		10 Signs.		9 Signs.		8 Signs.		7 Signs.		6 Signs.		Deg.
Add													

Table XVI. The Moon's Latitude in Eclipses.

Argument. Moon's equated Distance from the Node.				
0 Signs. *North Ascending.*				
6 Signs. *South Ascending.*				
°	°	'	"	°
0	0	0	0	30
1	0	5	15	29
2	0	10	30	28
3	0	15	45	27
4	0	20	59	26
5	0	26	13	25
6	0	31	26	24
7	0	36	39	23
8	0	41	51	22
9	0	47	22	21
10	0	52	13	20
11	0	57	23	19
12	1	2	31	18
13	1	7	38	17
14	1	12	44	16
15	1	17	49	15
16	1	22	52	14
17	1	27	53	13
18	1	32	52	12
19	1	37	49	11
5 Signs. *North Descending.*				
11 Signs. *South Descending.*				

This table shews the Moon's true latitude a little beyond the utmost limits of eclipses.

Table XVII. The Moon's horizontal Parallax, with the Semidiameters, and true Horary Motions of the Sun and Moon, to every sixth Degree of their mean Anomalies, the Quantities for the intermediate Degrees being easily proportioned by Sight.

Anomaly of Sun and Moon.		Moon's horizontal Parallax.		Sun's Semidiameter.		Moon's Semidiameter.		Moon's Horary Motion.		Sun's Horary Motion.		Anomaly of Sun and Moon.	
s.	°	′	″	′	″	′	″	′	″	′	″	′	″
0	0	54	29	15	50	14	54	30	10	2	23	12	0
	6	54	31	15	50	14	55	30	12	2	23		24
	12	54	31	15	50	14	56	30	51	2	23		18
	18	54	40	15	51	14	57	30	19	2	23		12
	24	54	47	15	51	14	58	30	20	2	23		6
1	0	54	6	15	52	14	59	30	34	2	24	11	0
	6	55	6	15	53	15	1	30	44	2	24		24
	12	55	17	15	54	15	4	30	55	2	24		18
	18	55	29	15	55	15	8	31	9	2	24		12
	24	55	42	15	56	15	12	31	23	2	25		6
2	0	55	56	15	58	15	17	31	40	2	25	10	0
	6	56	12	15	59	15	22	31	56	2	26		24
	12	56	29	16	1	15	26	32	17	2	27		18
	18	56	48	16	2	15	30	32	39	2	27		12
	24	57	8	16	4	15	36	33	11	2	28		6
3	0	57	30	16	6	15	41	33	23	2	28	9	0
	6	57	52	16	8	15	46	33	47	2	29		24
	12	58	12	16	10	15	52	34	11	2	29		18
	18	58	31	16	11	15	58	34	24	2	29		12
	24	58	49	16	13	16	3	34	58	2	30		6
4	0	59	6	16	14	16	9	35	22	2	30	8	0
	6	59	21	16	15	16	14	35	45	2	31		24
	12	59	35	16	17	16	19	36	0	2	31		18
	18	59	48	16	19	16	24	36	20	2	32		12
	24	60	0	16	20	16	28	36	40	3	32		6
5	0	60	11	16	21	16	31	37	0	2	32	7	0
	6	60	21	16	21	16	32	37	10	2	33		24
	12	60	30	16	22	16	37	37	19	2	33		18
	18	60	38	16	22	16	38	37	28	2	33		12
	24	60	45	16	23	16	39	37	36	2	33		6
6	0	60	45	16	23	16	39	37	40	2	33	6	0

To calculate the true Time of New or Full Moon.

Precept I. If the required time be within the limits of the 18th century, write out the mean time of new moon in March, for the proposed year, from Table I, in the old style, or from Table II, in the new; together with the mean anomalies of the Sun and Moon, and the Sun's mean distance from the Moon's ascending node. If you want the time of full moon in March, add the half lunation at the foot of Table III, with its anomalies, &c. to the former numbers, if the new moon falls before the 15th of March; but if it falls after, subtract the half lunation, with the anomalies, &c. belonging to it, from the former numbers, and write down the respective sums or remainders.

II. In these additions or subtractions, observe, that 60 seconds make a minute, 60 minutes make a degree, 30 degrees make a sign, and 12 signs make a circle. When you exceed 12 signs in addition, reject 12, and set down the remainder.— When the number of signs to be subtracted is greater than the number you subtract from, add 12 signs to the lesser number, and then you will have a remainder to set down. In the tables, signs are marked thus,^{s} degrees thus,$^{\circ}$ minutes thus,$'$ and seconds thus.$''$

III. When the required new or full moon is in any given month after March, write out as many lunations, with their anomalies, and the Sun's distance from the node, from Table III, as the given month is after March; setting them in order below the numbers taken out for March.

IV. Add all these together, and they will give the mean time of the required new or full moon, with the mean anomalies, and Sun's mean distance from the ascending node, which are the arguments for finding the proper equations.

V. With the number of days added together, enter Table IV under the given month; and against that number you have the day of mean new or full moon in the left-hand column, which set before the hours, minutes, and seconds, already found.

But (as it will sometimes happen) if the said number of days fall short of any in the column under the given month, add one lunation and its anomalies, &c. (from Table III), to the fore-

said sums, and then you will have a new sum of days wherewith to enter Table IV, under the given month, where you are sure to find it the second time, if the first falls short.

VI. With the signs and degrees of the Sun's anomaly, enter Table VII, and therewith take out the annual or first equation for reducing the mean syzygy to the true; taking care to make proportions in the table for the odd minutes and seconds of anomaly, as the table gives the equation only to whole degrees.

Observe, in this and every other case of finding equations, that if the signs are at the head of the table, their degrees are at the left hand, and are reckoned downwards; but if the signs are at the foot of the table, their degrees are at the right hand, and are counted upwards; the equation being in the body of the table, under or over the signs, in a collateral line with the degrees. The titles *Add* or *Subtract* at the head or foot of the tables where the signs are found, shew whether the equation is to be added to the mean time of new or full moon, or to be subtracted from it. In this table, the equation is to be *subtracted*, if the signs of the Sun's anomaly are found at the head of the table; but it is to be *added*, if the signs are at the foot.

VII. With the signs and degrees of the Sun's mean anomaly, enter Table VIII, and take out the equation of the Moon's mean anomaly; *subtract* this equation from her mean anomaly, if the signs of the Sun's anomaly be at the head of the table, but *add* it if they are at the foot; the result will be the Moon's equated anomaly, with which enter Table IX, and take out the second equation for reducing the mean to the true time of new or full moon; *adding* this equation, if the signs of the Moon's anomaly are at the head of the table, but *subtracting* it if they are at the foot, and the result will give you the mean time of the required new or full moon twice equated, which will be sufficiently near for common purposes. But when you want to calculate an eclipse, the following equations must be used.—Thus,

VIII. Subtract the Moon's equated anomaly from the Sun's mean anomaly, and with the remainder in signs and degrees enter Table X, and take out the third equation, applying it to the former equated time, as the titles, *Add* or *Subtract*, direct.

IX. With the Sun's mean distance from the ascending node, enter Table XI, and take out the equation answering to that

argument, *adding* it to, or *subtracting* it from, the former equated time, as the titles direct, and the result will give the time of new or full moon, agreeing with well regulated clocks or watches, very near the truth. But, to make it agree with the solar, or apparent time, apply the equation of natural days, found in the tables (from page 138 to page 156), as it is leap-year, or the first, second, or third after.

The method of calculating the time of any new or full moon without the limits of the 18th century, will be shewn further on; and a few examples compared with the precepts, will make the whole work plain.

N. B The tables begin the day at noon, and reckon forwards from thence to the noon following Thus, March the 31st, at 22h 30m 25s of tabular time, is April 1st (in common reckoning) at 30m 25s after 10 o'clock in the morning

Ex. I.—*Required the true time of New Moon in April 1764, New Style?*

By the Precepts	New Moon.				Sun's Anom				Moon's Anom.				Sun from node			
	D	H	M	S	S											
March 1764,	2	8	55	36	8	2	20	0	10	13	35	21	11	4	54	48
Add 1 Lunation,	29	12	44	3	0	29	6	19	0	25	49	0	1	0	40	11
Mean New Moon,	31	22	39	39	9	1	26	19	11	9	24	21	0	5	35	2
First Equation,	+	4	10	40	11	10	59	18	+	1	34	57				
Time once equated,	32	1	50	19	9	20	27	1	11	10	59	18	Sun from node and Arg 4th equation.			
Second Equation,	—	3	24	49	Arg 3d equat.				Arg 2d equat							
Time twice equated,	31	22	25	30												
Third Equation,		+	4	37												
Time thrice equated,	31	22	30	7												
Fourth Equation,			+	18												
True New Moon,	31	22	30	25												
Equation of days,		—	3	48												
Apparent time,	31	22	26	37												

So the true time is 22 h. 30 min. 25 sec. after the noon of the 31st March; that is, April 1st, at 30 min. 25 sec. after 10 in the morning. But the apparent time is 26 min. 37 sec after 10 in the morning.

Ex. II.—*Required the true time of Full Moon in May* 1762, *New Style?*

By the Precepts.	New Moon				Sun's Anom				Moon's Anom				Sun from node			
	D	H.	M	S	S.	°	′	″	S.	°	′	″	S.	°	′	″
March 1762,	24	15	18	24	8	23	48	16	1	23	39	11	10	18	49	14
Add 2 Lunations,	59	1	28	6	1	28	12	39	1	21	38	1	2	1	20	28
New Moon, May,	22	16	46	30	10	22	0	55	8	15	37	12	0	20	9	42
Subt ½ Lunation,	14	18	22	2	0	14	33	10	6	12	54	30	0	15	20	7
Full Moon, May,	7	22	24	28	10	7	27	45	9	2	42	42	0	4	49	35
First Equation,	+	3	16	36	9	3	57	18	+	1	14	36	Sun from node and Arg. 4th equation.			
Time once equated,	8	1	41	4	1	3	30	27	9	3	57	18				
Second Equation,	—	9	47	53	Arg 3d equat				Arg 2d equat.							
Time twice equated,	7	15	53	11												
Third Equation,		—	2	36												
Time thrice equated,	7	15	50	35												
Fourth Equation,			+	15												
True Full Moon,	7	15	50	50												

Ans. May 7th at 15 h. 50 min. 50 sec. past noon, viz May 8th, at 3 h. 50 min. 50 sec. in the morning.

To calculate the time of New and Full Moon in a given year and month of any particular century between the Christian era and the 18th century.

Precept I. Find a year of the same number in the 18th century with that of the year in the century proposed, and take out the mean time of new moon in March, old style, for that year, with the mean anomalies, and Sun's mean distance from the node at that time, as already taught.

II. Take as many complete centuries of years from Table VI, as, when subtracted from the above-said year in the 18th century, will answer to the given year; and take out the first mean new moon and its anomalies, &c. belonging to the said centuries, and set them below those taken out for March in the 18th century.

III. Subtract the numbers belonging to these centuries, from those of the 18th century, and the remainders will be the mean time and anomalies, &c. of new moon in March, in the given

year of the century proposed.—Then, work in all respects for the true time of new or full moon, as shewn in the above precepts and examples.

IV. If the days annexed to these centuries exceed the number of days from the beginning of March taken out in the 18th century, add a lunation and its anomalies, &c. from Table III, to the time and anomalies of new moon in March, and then proceed in all respects as above.—This circumstance happens in Example V.

Ex. III.—*Required the true time of Full Moon in April, Old Style* A. D. 30?

From 1730 subtract 1700 (or 17 centuries) and there remains 30.

By the Precepts.	New Moon				Sun's Anom.				Moon's Anom.				Sun from node			
	D.	H.	M.	S.	S.	°	′	″	S.	°	′	″	S.	°	′	″
March 1730,	7	12	34	16	8	18	4	31	9	0	32	17	1	23	17	16
Add ½ Lunation,	14	18	22	2	0	14	33	10	6	12	54	30	0	15	20	7
Full Moon,	22	6	56	18	9	2	37	41	3	13	28	47	2	8	37	23
1700 years subtract,	14	17	36	42	11	28	46	0	10	29	36	0	4	29	23	0
Full ☽ Mar. A. D. 30,	7	13	19	36	9	3	51	41	4	13	50	47	9	9	14	23
Add 1 Lunation,	29	12	44	3	0	29	6	19	0	25	49	0	1	0	40	14
Full Moon, April,	6	2	3	39	10	2	58	0	5	9	39	47	10	9	54	37
First Equation,	+	3	28	4	5	10	58	40	+	1	18	53	Sun from node			
Time once equated,	6	5	31	43	4	21	59	20	5	10	58	40	and Arg. 4th			
Second Equation,	+	2	57	48	Arg. 3d equat.				Arg. 2d equat.				equation.			
Time twice equated,	6	8	29	31												
Third Equation,		—	2	54												
Time thrice equated,	6	8	26	37												
Fourth Equation,		—	1	33												
Tr. Full Moon, Apr.	6	8	25	4												

Hence it appears that the true time of full Moon in April, A. D. 30, Old Style, was on the 6th day, at 25 m. 4 sec. past 8 in the evening.

To calculate the true time of New or Full Moon, in any given year and month before the Christian era.

Precept I. Find a year in the 18th century, which, being added to the given number of years before Christ, diminished by one, shall make a number of complete centuries.

II. Find this number of centuries in Table VI, and subtract the time and anomalies belonging to it, from those of the mean new moon in March, the above-found year of the 18th century, and the remainder will denote the time and anomalies, &c. of mean new moon in March, the given year before Christ.—Then, for the true time thereof, in any month of that year, proceed as above taught.

Ex. IV.—*Required the true time of New Moon in May, Old Style, the year before Christ 585?*

The years 584, added to 1716, make 2300, or 23 centuries.

By the Precepts.	New Moon.	Sun's Anom.	Moon's Anom.	Sun from node
	D. H. M. S.	s. ° ′ ″	s. ° ′ ″	s. ° ′ ″
March 1716,	11 17 33 29	8 22 50 39	4 4 14 2	4 27 17 5
2300 years subtract,	11 5 57 53	11 19 47 0	1 5 59 0	7 25 27 0
Mar. before Chr. 585,	0 11 35 36	9 3 3 39	2 28 15 2	9 1 50 5
Add 3 Lunations,	88 14 12 9	2 27 18 58	2 17 27 1	3 2 0 42
May before Chr. 585,	28 1 47 45	0 0 22 37	5 15 42 3	0 3 50 47
First Equation,	— 1 37	5 15 41 17	— 46	Sun from node
Time once equated,	28 1 46 8	6 14 41 20	5 15 41 17	and Arg. 4th
Second Equation,	+ 2 15 1	Arg. 3d equat.	Arg. 2d equat.	equation.
Time twice equated,	28 4 1 9			
Third Equation,	+ 1 9			
Time thrice equated,	28 4 2 18			
Fourth Equation,	+ 12			
True New Moon,	28 4 2 30			

So the true time was May 28, at 2 minutes 30 seconds past 4 in the afternoon.

These tables are calculated for the meridian of London, but they will serve for any other place, by subtracting four minutes from the tabular time, for every degree that the meridian of the given place is westward of London, or adding four minutes for every degree that the meridian of the given place is eastward: Thus—

Ex. V.—*Required the true time of Full Moon at Alexandria in Egypt, in September, Old Style, the year before Christ 201?*

The years 200 added to 1800, make 2000, or 20 centuries.

By the Precepts.	New Moon.				Sun's Anom.				Moon's Anom.				Sun from node			
	D.	H.	M.	S.	S.	°	′	″	S.	°	′	″	S.	°	′	″
March 1800,	13	0	22	17	8	23	19	55	10	7	52	36	11	3	58	24
Add 1 Lunation,	29	12	44	3	0	29	6	19	0	25	49	0	1	0	40	14
From the Sum,	42	13	6	20	9	22	26	14	11	3	41	36	0	4	38	38
Subtract 2000 years,	27	18	9	19	0	8	50	0	0	15	42	0	6	27	45	0
N.M. before Chr 201,	14	18	57	1	9	13	36	14	10	17	59	36	5	6	53	38
Add { 6 Lunations,	177	4	24	18	5	24	37	56	5	4	51	3	6	4	1	24
Add { half Lunation,	14	18	22	2	0	14	33	10	6	12	54	30	0	15	20	7
Full Moon, Sept.	22	17	43	21	3	22	47	20	10	5	48	9	11	26	15	9
First Equation,	—	3	52	6	10	4	19	55	—	1	28	14	Sun from node			
Time once equated,	22	13	51	15	5	18	27	25	10	4	19	55	and Arg. 4th			
Second Equation,	—	8	25	4	Arg 3d equat.				Arg. 2d equat.				equation.			
Time twice equated,	22	5	26	11												
Third Equation,			—	58												
Time thrice equated,	22	5	25	13												
Fourth Equation,			—	12												
True time at London,	22	5	25	1												
Add for Alexandria,		2	1	27												
True time there,	22	7	26	28												

Thus it appears that the true time of full Moon at Alexandria, in September, Old Style, the year before Christ 201, was the 22d day, at 26 minutes 28 seconds after 7 in the evening.

Ex. VI.—*Required the true time of Full Moon at Babylon in October, Old Style, in the 4008th year before the first year of Christ, or 4007 years before the year of his birth?*

The years 1007, added to 1793, make 5800, or 58 centuries.

By the Precepts.	New Moon.				Sun's Anom.				Moon's Anom.				Sun from node			
	D.	H.	M.	S.	S.	°	′	″	S.	°	′	″	S.	°	′	″
March 1793,	30	9	13	55	9	10	16	11	8	7	37	58	7	6	18	26
Subtract 5800 years,	15	12	38	7	10	21	35	0	6	24	43	0	9	13	4	0
N. M. bef. Chr. 4007,	14	20	35	48	10	18	41	11	1	12	54	58	9	23	17	26
Add 7 Lunations,	206	17	8	21	6	23	44	15	6	0	43	3	7	4	41	38
Add half Lunation,	14	18	22	2	0	14	33	10	6	12	54	30	0	15	20	7
Full Moon, October,	22	8	6	11	5	26	58	36	1	26	32	31	5	13	19	11
First Equation,		—	13	26	1	26	27	26		—	5	5	Sun from node			
Time once equated,	22	7	52	45	4	0	31	10	1	26	27	26	and Arg. 4th			
Second Equation,	+	8	29	21	Arg. 3d equat.				Arg. 2d equat.				equation.			
Time twice equated,	22	16	22	6												
Third Equation,		—	4	10												
Time thrice equated,	22	16	17	56												
Fourth Equation,			—	51												
Full Moon at London,	22	16	17	5												
Add for Babylon,		2	25	41												
True time there,	22	18	42	46												

So that, on the meridian of London, the true time was October 23, at 17 min. 5 sec. past 4 in the morning; but at Babylon, the true time was October 23, at 42 min. 46 sec. past 6 in the morning. —This is supposed by some to have been the year of the creation.

To calculate the true time of New or Full Moon in any given year and month after the 18th century.

Precept I. Find a year of the same number in the 18th century with that of the year proposed, and take out the mean time and anomalies, &c. of new moon in March, old style, for that year, in Table I.

II. Take so many years from Table VI, as, when added to the above-mentioned year in the 18th century, will answer to the given year in which the new or full moon is required: and take out the first new moon, with its anomalies, for these complete centuries.

III. Add all these together, and then work in all respects as above shewn, only remember to subtract a lunation and its anomalies, when the above-said addition carries the new moon beyond the 31st of March, as in the following Example.

Ex. VII.—*Required the true time of New Moon in July, Old Style,* A. D. 2180?

Four centuries, or 400 years, added to A. D. 1780, make 2180.

By the Precepts.	New Moon.				Sun's Anom.				Moon's Anom.				Sun from node			
	D.	H.	M.	S.	S.	°	′	″	S.	°	′	″	S.	°	′	″
March 1780,	23	23	1	44	9	4	18	13	1	21	7	47	10	18	21	1
Add 400 years,	17	8	43	29	0	13	24	0	10	1	28	0	6	17	49	0
From the sum,	41	7	45	13	9	17	42	13	11	22	35	47		6	10	1
Subtract 1 Lunation,	29	12	44	3	0	29	6	19	0	25	49	0		0	40	14
New ☽ March 2180,	11	19	1	10	8	18	35	54	10	26	46	47	4	5	29	47
Add 4 Lunations,	118	2	56	12	3	26	25	17	3	13	16	2	4	2	40	56
New ☽ July 2180,	7	21	57	22	0	15	1	11	2	10	2	49	8	8	10	43
First Equation,	—	1	3	39	3	9	38	37		—	24	12	Sun from node and Arg. 4th equation.			
Time once equated,	7	20	53	43	10	5	22	34	2	9	38	37				
Second Equation,	+	9	24	8	Arg. 3d equat.				Arg. 2d equat.							
Time twice equated,	8	6	17	51												
Third Equation,		+	3	50												
Time thrice equated,	8	6	21	47												
Fourth Equation,		+	1	8												
True time, July,	8	6	22	55												

True time, July 8, at 22 min. 55 sec. past 6 in the evening.

In keeping by the old style, we are always sure to be right, by adding or subtracting whole hundreds of years to or from any given year in the 18th century. But in the new style we may be very apt to make mistakes, on account of the leap-year's not coming in regularly every fourth year: and therefore, when we go without the limits of the 18th century, it will be better to keep by the old style, and, at the end of the calculation, reduce the time to the new. Thus, in the 22d century, there will be 14 days difference between the styles; and therefore, the true time of new moon in this last example being reduced to the new style, will be the 22d of July, at 22 minutes 55 seconds past 6 in the evening.

To calculate the true place of the Sun for any given moment of time.

Precept I. In Table XII, find the next lesser year in number to that in which the Sun's place is sought, and write out his mean longitude and anomaly answering thereto: to which add his mean motion and anomaly for the complete residue of years, months, days, hours, minutes, and seconds, down to the given time, and this will be the Sun's mean place and anomaly at that time, in the old style, provided the said time be in any year after the Christian era. *See the first following Example.*

II. Enter Table XIII, with the Sun's mean anomaly, and making proportions for the odd minutes and seconds thereof, take out the equation of the Sun's centre: which, being applied to his mean place as the title *Add* or *Subtract* directs, will give his true place or longitude from the vernal equinox, at the time for which it was required.

III. To calculate the Sun's place for any time in a given year before the Christian era, take out his mean longitude and anomaly for the first year thereof, and from these numbers subtract the mean motions and anomalies for the complete hundreds or thousands next above the given year; and, to the remainders, add those for the residue of years, months, &c. and then work in all respects as above. *See the second Example following.*

Ex. I.—*Required the Sun's true place, March 20, Old Style, 1764, at 22 hours 30 minutes 25 seconds past noon?—In common reckoning, March 21, at 10 hours 30 minutes 25 seconds in the forenoon.*

		Sun's Longit.				Sun's Anom.			
		s.	°	′	″	s.	°	′	″
To the radical year after Christ 1701		9	20	43	50	6	13	1	0
Add complete years	60	0	0	27	12	11	29	26	0
	2	11	29	17	8	11	29	14	0
	March	1	28	9	11	1	28	9	0
Bissextile, Days	20		20	41	55		20	41	55
Hours	22			54	13			54	13
Minutes	30			1	14			1	14
Seconds	25				1				1
Sun's mean place at the given time		0	10	14	36	9	1	27	22
Equation of the Sun's centre, add			1	55	36	Mean Anom.			
Sun's true place at the same time		0	12	10	12 or ♈	12	10	12	

Ex. II.—*Required the Sun's true place, October 23, Old Style, at 16 hours 57 minutes past noon, in the 4800th year before the year of Christ 1; which was the 4007th before the year of his birth, and the year of the Julian period 706?*

By the Precepts.

		Sun's Longit. s.	°	′	″	Sun's Anom. s.	°	′	″
From the radical numbers after Christ	1	9	7	53	10	6	28	48	0
Subtract those for 5000 complete years		1	7	46	40	10	13	25	9
Remains for a new radix		8	0	6	30	8	15	23	0
To which add, to bring it to the given time, complete years	900	0	6	48	0	11	21	37	0
	80	0	0	36	16	11	29	15	0
	12	0	0	5	20	11	29	53	0
	October	8	29	4	54	8	29	4	0
	Days 23		22	40	12		22	40	12
	Hours 16			39	26			39	26
	Minutes 57			2	20			2	29
Sun's mean place at the given time		6	0	3	4	5	28	33	58
Equation of the Sun's centre subtract				3	4	Sun's Anom.			
Sun's true place at the same time		6	0	0	0 or ♎	0	0	0	

So that in the meridian of London, the Sun was then just entering the sign ♎ Libra, and, consequently, was upon the point of the autumnal equinox.

If to the above time of the autumnal equinox at London, we add 2 hours 25 minutes 41 seconds for the longitude of Babylon, we shall have for the time of the same equinox at that place, October 23d, at 19 hours 22 minutes 41 seconds; which, in the common way of reckoning, is October 24th, at 22 minutes 41 seconds past 7 in the morning.[1]

[1] The reason why this calculation makes the autumnal equinox, in the year of the Julian period 706, to be two days sooner than the time of the same equinox mentioned in § 218, is, that in that page, only the mean time is taken into the account, as if there was no equation of the Sun's motion.

The equation at the autumnal equinox then, did not exceed an hour and a quarter, when reduced to time. But, in the year of Christ 1756, which was 5763 years after, the equation at the autumnal equinox amounted to 1 day 22 hours 24 minutes, by which quantity, the true time fell later than the mean. So that, if we consider the *true* time of this last-mentioned equinox, only as mean time, the mean motion of the Sun carried thence back to the autumnal equinox in the year of the Julian period 706, will fix it to the 25th of October in that year.

And it appears by Example VI, that in the same year, the true time of full moon at Babylon was October 23d, at 42 minutes 46 seconds after 6 in the morning; so that the autumnal equinox was on the day next after the day of full moon. The dominical letter for that year was G, and consequently the 24th of October was on a Wednesday.

To find the Sun's distance from the Moon's ascending Node, at the time of any given New or Full Moon; and, consequently, to know whether there is an Eclipse at that time or not.

The Sun's distance from the Moon's ascending node, is the argument for finding the Moon's fourth equation in the syzygies, and therefore it is taken into all the foregoing examples in finding the times thereof. Thus, at the time of mean new moon in April 1764, the Sun's mean distance from the ascending node, is $0^s\ 5^\circ\ 35'\ 2''$. *See Example I, p. 282.*

The descending node is opposite to the ascending one, and they are just six signs distant from each other.

When the Sun is within 17 degrees of either of the nodes at the time of new moon, he will be eclipsed at that time: and when he is within 12 degrees of either of the nodes at the time of full moon, the Moon will be then eclipsed. Thus we find that, there will be an eclipse of the Sun at the time of new moon in April 1764.

But the true time of that new moon comes out by the equations to be 50 minutes 46 seconds later than the mean time thereof, by comparing these times in the above example; and, therefore, we must add the Sun's motion from the node during that interval, to the above mean distance $0^s\ 5^\circ\ 35'\ 2''$, which motion is found in Table XII for 50 minutes 46 seconds, to be $2'\ 12''$. And to this we must apply the equation of the Sun's mean distance from the node in Table XV, found by the Sun's anomaly, which, at the mean time of new moon in Example I, is $9^s\ 1^\circ\ 26'\ 19''$; and then we shall have the Sun's true distance from the node, at the true time of new moon, as follows:

	Sun from Node s ° ′ ″
At the mean time of new moon in April 1764	0 5 35 2
Sun's motion from the node for { 50 minutes	2 10
{ 46 minutes	2
Sun's mean distance from node at true new moon	0 5 37 14
Equation of mean distance from node, add	2 5 0
Sun's true distance from the ascending node	0 7 42 11

Which being far within the above limit of 17 degrees, shews that the Sun must then be eclipsed.

And now we shall shew how to project this, or any other eclipse, either of the Sun or Moon.

To project an Eclipse of the Sun.

On the projection of solar eclipses.

In order to do this, we must find the ten following elements, by means of the tables.

1. The true time of conjunction of the Sun and Moon; and at that time, 2. The semidiameter of the Earth's disc, as seen from the Moon, which is equal to the Moon's horizontal parallax. 3. The Sun's distance from the solstitial colure to which he is then nearest. 4. The Sun's declination. 5. The angle of the Moon's visible path with the ecliptic. 6 The Moon's latitude. 7 The Moon's true horary motion from the Sun. 8. The Sun's semidiameter. 9. The Moon's. 10. The semidiameter of the penumbra.

We shall now proceed to find these elements for the Sun's eclipse in April 1764.

To find the true time of new moon.—This, by Example I, p. 282, is found to be on the first day of the said month, at 30 minutes 25 seconds after 10 in the morning.

2. *To find the Moon's horizontal parallax, or semidiameter of the Earth's disc, as seen from the Moon.*—Enter Table XVII, with the signs and degrees of the Moon's anomaly (making proportions, because the anomaly is in the table only to every 6th degree), and thereby take out the Moon's horizontal parallax; which, for the above time, answering to the anomaly 11s 9° 24′ 21″, is 54′ 53″.

3. *To find the Sun's distance from the nearest solstice, viz. the beginning of Cancer, which is 3s or 90° from the beginning of Aries.*—It appears by the example on page 289, (where the

Sun's place is calculated to the above time of new moon) that the Sun's longitude from the beginning of Aries, is then 0ˢ 12° 10′ 12″, that is, the Sun's place at that time is ♈ Aries, 12° 10′ 12″.

Therefore, from	3	0	0	0
Subtract the Sun's longitude or place	0	12	10	12
Remains the Sun's distance from the solstice ♋	2	17	49	48

Or 77° 49′ 48″; each sign containing 30 degrees.

4. *To find the Sun's declination.*—Enter Table XIV, with the signs and degrees of the Sun's true place, viz. 0ˢ 12°, and making proportions for the 10′ 12″, take out the Sun's declination answering to his true place, and it will be found to be 4° 49′ north.

5. *To find the Moon's latitude.*—This depends on her distance from her ascending node, which is the same as the Sun's distance from it at the time of new moon; and is thereby found in Table XVI.

But we have already found, that the Sun's equated distance from the ascending node, at the time of new moon in April 1764, is 0ˢ 7° 42′ 14″. See p. 292

Therefore, enter Table XIV, with 0 signs at the top, and 7 and 8 degrees at the left hand, and take out 36′ and 39″, the latitude for 7°; and 41′ 51″, the latitude for 8°; and by making proportions between these latitudes for the 42′ 14″, by which the Moon's distance from the node exceeds 7 degrees; her true latitude will be found to be 40′ 18″ north ascending.

6. *To find the Moon's true horary motion from the Sun.*—With the Moon's anomaly, viz. 11ˢ 9° 24′ 21″, enter Table XVII, and take out the Moon's horary motion; which, by making proportions in that table, will be found to be 30′ 22″. Then, with the Sun's anomaly, 9ˢ 1° 26′ 19″, take out his horary motion 2′ 28″ from the same table; and subtracting the latter from the former, there will remain 27′ 54″ for the Moon's true horary motion from the Sun.

7. *To find the angle of the Moon's visible path with the ecliptic.*—This, in the projection of eclipses, may be always rated at 5° 35′, without any sensible error.

8, 9. *To find the semidiameters of the Sun and Moon.*—These are found in the same table, and by the same arguments,

as their horary motions. In the present case, the Sun's anomaly gives his semidiameter 16′ 6″, and the Moon's anomaly gives her semidiameter 14′ 57″.

10. *To find the semidiameter of the penumbra.*—Add the Moon's semidiameter to the Sun's, and their sum will be the semidiameter of the penumbra, viz. 31′ 3″.

Now, collect these elements, that they may be found the more readily when they are wanted in the construction of this eclipse.

	D.	H.	M.	S.
1. True time of new moon in April 1764,	1	10	30	25
	°	′	″	
2. Semidiameter of the Earth's disc,	0	54	53	
3. Sun's distance from the nearest solstice,	77	40	48	
4. Sun's declination, north,	4	40	0	
5. Moon's latitude, north ascending,	0	40	18	
6. Moon's horary motion from the Sun,	0	27	54	
7. Angle of the Moon's visible path with the ecliptic,	5	35	0	
8. Sun's semidiameter,		16	6	
9. Moon's semidiameter,		14	57	
10. Semidiameter of the penumbra,		31	3	

To project an Eclipse of the Sun geometrically.

On the projection of solar eclipses. Plate XII. Fig. 1.

Make a scale of any convenient length, as AC, and divide it into as many equal parts as the Earth's semi-disc contains minutes of a degree; which, at the time of the eclipse in April 1764, is 54′ 53″. Then, with the whole length of the scale as a radius, describe the semicircle AMB upon the centre C; which semicircle shall represent the northern half of the Earth's enlightened disc, as seen from the Sun.

Upon the centre C raise the straight line CH, perpendicular to the diameter ACB; and ACB shall be a part of the ecliptic, and CH its axis.

Being provided with a good sector,* open it to the radius CA in the line of chords; and, taking from thence the chord of 23½ degrees in your compasses, set it off both ways from H, to g and to h, in the periphery of the semi-disc; and draw the straight line gVh, in which the north pole of the disc will be always found.

* A method of projecting an eclipse of the Sun, with the aid only of a ruler and pair of compasses, will be found in Ferguson's Lady's and Gentleman's Astronomy.

When the Sun is in *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, and *Virgo*, the north pole of the Earth is enlightened by the Sun: but whilst the Sun is in the other six signs, the south pole is enlightened, and the north pole is in the dark.

And when the Sun is in *Capricorn*, *Aquarius*, *Pisces*, *Aries*, *Taurus*, and *Gemini*, the northern half of the Earth's axis *C* XII *P* lies to the right hand of the axis of the ecliptic, as seen from the Sun; and to the left hand, whilst the Sun is in the other six signs.

Open the sector till the radius (or distance of the two 90's) of the sines be equal to the length of *Vh*, and take the sine of the Sun's distance from the solstice 77° 49′ 48″ as nearly as you can guess, in your compasses, from the line of sines, and set off that distance from *V* to *P* in the line *gVh*, because the Earth's axis lies to the right hand of the axis of the ecliptic in this case, the Sun being in Aries; and draw the straight line *C* XII *P* for the Earth's axis, of which *P* is the north pole. If the Earth's axis had lain to the left hand from the axis of the ecliptic, the distance *VP* would have been set off from *V* towards *g*.

To draw the parallel of latitude of any given place, suppose London, or the path of that place on the Earth's enlightened disc as seen from the Sun, from sun-rise till sun-set,* take the following method.

Subtract the latitude of London, 51½° from 90°, and the remainder 38½° will be the co-latitude, which take in your compasses from the line of chords, making *CA* or *CB* the radius, and set it from *h*, where the Earth's axis meets the periphery of the disc, to VI and VI, and draw the occult, or *dotted line* VI *K* VI. Then, from the points where this line meets the Earth's disc, set off the chord of the Sun's declination 4° 49′ to *D* and *F*, and to *E* and *G*, and connect these points by the two occult lines *F* XII *G*, and *D L E*.

Bisect *LK* XII in *K*, and through the point *K* draw the *black line* VI *K* VI. Then making *CB* the radius of a line of sines on the sector, take the co-latitude of London 38½° from the sines in your compasses, and set it both ways from *K*, to VI and VI. These hours will be just in the edge of the disc at the equinoxes, but at no other time in the whole year.

With the extent *K* VI taken into your compasses, set one foot in *K* (in the *black line* below the *occult one*) as a centre, and with the other foot describe the semicircle VI, 7, 8, 9, 10, &c

and divide it into 12 equal parts. Then, from these points of division, draw the occult lines 7 *p*, 8 *o*, 9 *n*, &c. parallel to the Earth's axis, *C* XII *P*.

With the small extent *K* XII as a radius, describe the quadrantal arc XII *f*, and divide it into six equal parts, as XII *a*, *a b*, *b c*, *c d*, *d e*, and *e f*; and through the division points, *a*, *b*, *c*, *d*, *e*, draw the occult lines VII *e* V, VIII *d* IV, IX *c* III, X *b* II, and XI *a* I, all parallel to VI *K* VI, and meeting the former occult lines 7 *p*, 8 *o*, &c. in the points VII, VIII, IX, X, XI, V, IV, III, II, and I: which points will mark the several situations of London on the Earth's disc, at these hours respectively, as seen from the Sun; and the elliptic curve VI VII VIII, &c. being drawn through these points, will represent the parallel of latitude, or path of London on the disc, as seen from the Sun, from its rising to its setting.

N. B. If the Sun's declination had been south, the diurnal path of London would have been on the upper side of the line VI *K* VI, and would have touched the line *DLE* in *L*.—It is requisite to divide the horary spaces into quarters (as some are in the figure), and, if possible, into minutes also.

Make *CB* the radius of a line of chords on the sector, and taking therefrom the chord of 5° 35′, the angle of the Moon's visible path with the ecliptic, set it off from *H* to *M* on the left hand of *CH*, the axis of the ecliptic, because the Moon's latitude is north ascending. Then draw *CM* for the axis of the Moon's orbit, and bisect the angle *MCH* by the right-line *CZ*.—If the Moon's latitude had been north descending, the axis of her orbit would have been on the right hand from the axis of the ecliptic.

N. B. The axis of the Moon's orbit lies the same way when her latitude is south ascending, as when it is north ascending; and the same way when south descending, as when north descending.

Take the Moon's latitude 40′ 18″ from the scale *CA* in your compasses, and set it from *i* to *x* in the bisecting line *C Z*, making *i x* parallel to *C y*: and through *x*, at right angles to the axis of the Moon's orbit *CM*, draw the straight line *N w x y S* for the path of the penumbra's centre over the Earth's disc. The point *w*, in the axis of the Moon's orbit, is that where the penumbra's centre approaches nearest to the centre of the Earth's disc, and consequently is the middle of the general eclipse: the

point x is that where the conjunction of the Sun and Moon falls, according to equal time by the tables; and the point y is the ecliptical conjunction of the Sun and Moon.

Take the Moon's true horary motion from the Sun, 27′ 54″, in your compasses, from the scale CA (every division of which is a minute of a degree), and with that extent make marks along the path of the penumbra's centre; and divide each space from mark to mark, into 60 equal parts or horary minutes, by dots; and set the hours to every 60th minute, in such a manner, that the dot signifying the instant of new moon by the tables, may fall into the point x, half way between the axis of the Moon's orbit, and the axis of the ecliptic; and then, the rest of the dots will shew the points on the Earth's disc, where the penumbra's centre is at the instants denoted by them, in its transit over the Earth.

Apply one side of a square to the line of the penumbra's path, and move the square backwards and forwards, until the other side of it cuts the same hour and minute (as at m and m) both in the path of London, and in the path of the penumbra's centre: and the particular minute or instant which the square cuts at the same time in both paths, will be the instant of the visible conjunction of the Sun and Moon, or greatest obscuration of the Sun, at the place for which the construction is made, namely, London, in the present example; and this instant is at 47½ minutes past X o'clock in the morning, which is 17 minutes 5 seconds later than the tabular time of true conjunction.

Take the Sun's semidiameter, 16′ 6″, in your compasses, from the scale CA, and setting one foot in the path of London at m, namely, at 47½ minutes past X, with the other foot describe the circle UY, which shall represent the Sun's disc as seen from London at the greatest obscuration. Then take the Moon's semidiameter, 14′ 57″, in your compasses, from the same scale; and setting one foot in the path of the penumbra's centre at m, in the 47½ minute after X; with the other foot describe the circle TY for the Moon's disc, as seen from London, at the time when the eclipse is at the greatest; and the portion of the Sun's disc which is hid or cut off by the Moon's, will shew the quantity of the eclipse at that time; which quantity may be measured on a line equal to the Sun's diameter, and divided into twelve equal parts for digits.

Lastly, take the semidiameter of the penumbra, 31′ 3″, from the scale Cd, in your compasses; and setting one foot in the line of the penumbra's central path, on the left hand from the axis of the ecliptic, direct the other foot towards the path of London; and carry that extent backwards and forwards, till both the points of the compasses fall into the same instants in both the paths: and these instants will denote the time when the eclipse begins at London. Then, do the like on the right hand of the axis of the ecliptic; and where the points of the compasses fall into the same instants in both the paths, they will shew at what time the eclipse ends at London.

These trials give 20 minutes after IX in the morning for the beginning of the eclipse at London, at the points N and O; 47½ minutes after X, at the points m and m, for the time of greatest obscuration; and 18 minutes after XII, at R and S, for the time when the eclipse ends, according to mean or equal time.

From these times we must subtract the equation of natural days, viz. 3 minutes 48 seconds, in leap year April 1, and we shall have the apparent times; namely, IX hours 16 minutes 12 seconds for the beginning of the eclipse, X hours 43 minutes 42 seconds for the time of greatest obscuration, and XII hours 14 minutes 12 seconds for the time when the eclipse ends. But the best way is to apply this equation to the true equal time of new moon, before the projection be begun, as is done in Example I. For the motion or position of places on the Earth's disc answers to apparent or solar time.

In this construction, it is supposed, that the angle under which the Moon's disc is seen, during the whole time of the eclipse, continues invariably the same; and that the Moon's motion is uniform and rectilineal during that time. But these suppositions do not exactly agree with the truth; and, therefore, supposing the elements given by the tables to be accurate, yet the times and phases of the eclipse, deduced from its construction, will not answer to exactly what passes in the heavens; but may be at least two or three minutes wrong, though done with the greatest care. Moreover, the paths of all places of considerable latitudes are nearer the centre of the Earth's disc, as seen from the Sun, than those constructions make them; because the disc is projected as if the Earth were a perfect sphere, although it is known to be a spheroid. Consequently, the Moon's

shadow will go farther northward in all places of northern latitude, and farther southward in all places of southern latitude, than it is shewn to do in these projections.—According to Meyer's tables, this eclipse will be about a quarter of an hour sooner than either these tables, or Mr. Flamstead's; or Dr. Halley's make it: and will not be annular at London. But M. De la Caille's make it almost central.

The Projection of Lunar Eclipses.

When the Moon is within 12 degrees of either of her nodes, at the time when she is full, she will be eclipsed, otherwise not. On the projection of lunar eclipses.

We find by Example II, page 283, that at the time of mean full moon in May 1762, the Sun's distance from the ascending node was only 4° 49′ 35″; and the Moon being then opposite to the Sun, must have been just as near her descending node, and was therefore eclipsed.

The elements for constructing an eclipse of the Moon are eight in number, as follow:—

1. The true time of full moon; and at that time, 2. The Moon's horizontal parallax. 3. The Sun's semidiameter. 4. The Moon's semidiameter. 5. The semidiameter of the Earth's shadow at the Moon. 6. The Moon's latitude. 7. The angle of the Moon's visible path with the ecliptic. 8. The Moon's true horary motion from the Sun.—Therefore,

1. *To find the true time of full Moon.*—Work as already taught in the precepts.—Thus we have the true time of full Moon in May 1762 (see Example II, page 283) on the 8th day, at 50 minutes 50 seconds past 3 o'clock in the morning.

2. *To find the Moon's horizontal parallax.*—Enter Table XVII, with the Moon's mean anomaly (at the above full) 9ˢ 2° 42′ 42″, and with it take out her horizontal parallax; which, by making the requisite proportions, will be found to be 57′ 23″.

3, 4. *To find the semidiameters of the Sun and Moon.*—Enter Table XVII, with their respective anomalies, the Sun's being 10ˢ 7° 27′ 45″ (by the above example), and the Moon's 9ˢ 2°

42′ 42″; and with these take out their respective semidiameters; the Sun's 15′ 56″, and the Moon's 15′ 38″.

5. *To find the semidiameter of the Earth's shadow at the Moon.*—Add the Sun's horizontal parallax, which is always 9″, to the Moon's, which in the present case is 57′ 23″, the sum will be 57′ 32″, from which subtract the Sun's semidiameter 15′ 56″, and there will remain 41′ 36″ for the semidiameter of that part of the Earth's shadow which the Moon then passes through.

6. *To find the Moon's latitude.*—Find the Sun's true distance from the ascending node (as already taught in page 291) at the true time of full moon; and this distance, increased by six signs, will be the Moon's true distance from the same node, and consequently the argument for finding her true latitude, as shewn in page 293.

Thus, in Example II, the Sun's mean distance from the ascending node was 0s 4° 49′ 35″, at the time of mean full moon: but it appears by the example, that the true time thereof was 6 hours 33 minutes 38 seconds sooner than the mean time, and therefore we must subtract the Sun's motion from the node (found in Table XII, page 272–3) during this interval, from the above mean distance 0s 4° 49′ 35″, in order to have his mean distance from it at the true time of full moon.—Then to this apply the equation of his mean distance from the node, found in Table XV, by his mean anomaly 10s 7° 27′ 45″; and, lastly, add six signs: so shall the Moon's true distance from the ascending node be found as follows:—

		s	°	′	″
Sun from node at mean full Moon,		0	4	49	35
His motion from it in	6 hours			15	35
	33 minutes			1	26
	38 seconds				2
Sum, subtract from the uppermost line,				17	3
Remains his mean distance at true full Moon,		0	4	32	32
Equation of his mean distance, add			1	38	0
Sun's true distance from the node,		0	6	10	32
To which add		6	0	0	0
And the sum will be		6	6	10	32

Which is the Moon's true distance from her ascending node at the true time of her being full; and consequently the argument for finding her true latitude at that time. Therefore, with this argument, enter Table XVI, making proportions between the latitudes belonging to the 6th and 7th degree of the argument at the left hand (the signs being at the top) for the 10′ 32″, and it will give 32′ 21″ for the Moon's true latitude, which appears by the table to be south descending.

7. *To find the angle of the Moon's visible path with the Ecliptic.*—This may be stated at 5° 35′, without any error of consequence in the projection of the eclipse.

8. *To find the Moon's true horary motion from the Sun.*—With their respective anomalies take out their horary motions from Table XVII, in page 279; and the Sun's horary motion subtracted from the Moon's, leaves remaining the Moon's true horary motion from the Sun; in the present case 30′ 52″.

Now collect these elements together for use.

	D.	H.	M.	S.
1. True time of full Moon in May 1762, - -	8	3	50	50
		°	′	″
2. Moon's horizontal parallax, - - -		0	57	23
3. Sun's semidiameter, - - - -		0	15	56
4. Moon's semidiameter, - - -		0	15	38
5. Semidiameter of the Earth's shadow at the Moon, -		0	41	36
6. Moon's true latitude, south descending, -		0	32	21
7. Angle of her visible path with the ecliptic, -		5	35	0
8. Her true horary motion from the Sun, - -		0	30	52

These elements being found for the construction of the Moon's eclipse in May 1762, proceed as follows:—

Make a scale of any convenient length, as *W X*, and divide it into 60 equal parts, each part standing for a minute of a degree. Plate XII. Fig. 2.

Draw the right line *A C B* (Fig. 3) for part of the ecliptic, and *C D* perpendicular thereto for the southern part of its axis; the Moon having south latitude. Fig. 3.

Add the semidiameters of the Moon and Earth's shadow together, which, in this eclipse, will make 57′ 15″; and take this from the scale in your compasses, and setting one foot in the point *C* as a centre, with the other foot describe the semicircle *A D B*; in one point of which, the Moon's centre will

be at the beginning of the eclipse, and in another at the end thereof.

Take the semidiameter of the Earth's shadow, 41′ 37″, in your compasses from the scale, and setting one foot in the centre *C*, with the other foot describe the semicircle *K L M* for the southern half of the Earth's shadow, because the Moon's latitude is south in this eclipse.

Make *C D* equal to the radius of a line of chords on the sector, and set off the angle of the Moon's visible path with the ecliptic, 5° 35′, from *D* to *E*, and draw the right line *C F E* for the southern half of the axis of the Moon's orbit, lying to the right hand from the axis of the ecliptic *C D*, because the Moon's latitude is south descending.—It would have been the same way (on the other side of the ecliptic) if her latitude had been north descending; but contrary in both cases, if her latitude had been either north ascending or south ascending.

Bisect the angle *D C E* by the right line *C g*: in which line, the true equal time of opposition of the Sun and Moon falls, as given by the tables.

Take the Moon's latitude, 32′ 21″, from the scale with your compasses, and set it, from *C* to *G*, in the line *C G g*; and through the point *G*, at right angles to *C F E*, draw the right line *P H G F N* for the path of the Moon's centre. Then, *F* shall be the point in the Earth's shadow, where the Moon's centre is at the middle of the eclipse; *G*, the point where her centre is at the tabular time of her being full; and *H*, the point where her centre is at the instant of her ecliptical opposition.

Take the Moon's horary motion from the Sun, 30′ 52″, in your compasses from the scale; and with that extent make marks along the line of the Moon's path *P G N*: then divide each space from mark to mark, into 60 equal parts, or horary minutes, and set the hours to the proper dots in such a manner, that the dot signifying the instant of full moon (viz. 50 minutes 50 seconds after III in the morning), may be in the point *G*, where the line of the Moon's path cuts the line that bisects the angle *D C E*.

Take the Moon's semidiameter, 15′ 38″, in your compasses from the scale, and with that extent, as a radius, upon the points *N*, *F*, and *P*, as centres, describe the circle *Q* for the Moon at the beginning of the eclipse, when she touches the

Earth's shadow at V; the circle *R* for the Moon at the middle of the eclipse; and the circle *S* for the Moon at the end of the eclipse, just leaving the Earth's shadow at *W*.

The point *N* denotes the instant when the eclipse begins, namely, at 15 minutes 10 seconds after II in the morning: the point *F*, the middle of the eclipse, at 47 minutes 45 seconds past III; and the point *P* the end of the eclipse, at 18 minutes after V. At the greatest obscuration, the Moon is 10 digits eclipsed.

Concerning an ancient Eclipse of the Moon.

It is recorded by Ptolemy, from Hipparchus, that on the 22d of September, the year 201 before the first year of Christ, the Moon rose so much eclipsed at Alexandria, that the eclipse must have begun about half an hour before she rose.

Mr. Carey puts down this eclipse in his chronology as follows, among several other ancient ones, recorded by different authors.

Jul. Per.	Ecl. ☾ *Per. Cal.* 2 *An.* 54. *Hor.* 7.	*Nabonassar*
4513.	*P. M. Alexandr. Dig. eccl.* 10.	547.
Sept. 22.	[*Ptolem. l.* 4, *c.* 11.]	*Mesor.* 16.

That is, in the 4513th year of the Julian period, which was the 547th year from Nabonassar, and the 54th year of the second Calippic period, on the 16th day of the month Mesori, which answers to the 22d of September, the Moon was 10 digits eclipsed at Alexandria, at 7 o'clock in the evening.

Now, as our Saviour was born, according to the Dionysian, or vulgar era of his birth, in the 4713th year of the Julian period, it is plain that the 4513th year of that period was the 200th year before the year of Christ's birth; and consequently 201 years before the year of Christ 1.

And, in the year 201, on the 22d of September, it appears by Example V (page 286), that the Moon was full at 26 minutes 28 seconds past 7 in the evening, in the meridian of Alexandria.

At that time, the Sun's place was Virgo 26° 14′, according to our tables; so that the Sun was then within 4 degrees of the autumnal equinox: and according to calculation, he must have set at Alexandria about 5 minutes after 6, and about one degree north of the west.

The Moon being full at that time, would have risen just at sunset, about one degree south of the east, if she had been in either of her nodes, and her visible place not depressed by parallax.

But her parallactic depression (as appears from her anomaly, viz. 10s 6° nearly), must have been 55′ 17″; which exceeds her whole diameter by 24′ 58″; but then, she must have been elevated 33′ 45″ by refraction; which, subtracted from her parallax, leaves 21′ 32″ for her visible or apparent depression.

And her true latitude was 30½′ north descending, which being contrary to her apparent depression, and greater than the same by 8′ 58″, her true time of rising must have been just about VI o'clock.

Now, as the Moon rose about one degree south of the east at Alexandria, where the visible horizon is land, and not sea, we can hardly imagine her to have been less than 15 or 20 minutes of time above the true horizon before she was visible.

Fig. 4. It appears by Fig. 4, which is a delineation of this eclipse reduced to the time at Alexandria, that the eclipse began at 53 minutes after V in the evening; and consequently 7 minutes before the Moon was in the true horizon; to which, if we add 20 minutes for the interval between her true rising and her being visible, we shall have 27 minutes for the time that the eclipse was begun before the Moon was visibly risen. The middle of this eclipse was at 30 minutes past VII, when its quantity was almost 10 digits, and its ending was at 6 minutes past IX in the evening. So that our tables come as near to the recorded time of this eclipse as can be expected, after a lapse of 1960 years.

CHAP. XX.

OF THE FIXED STARS.

Why the fixed stars appear bigger when viewed by the bare eye, than when seen through a telescope.

354. The stars are said to be fixed, because they have been generally observed to keep at the same distances from each other; their apparent diurnal revolutions being caused solely by the Earth's turning on its axis. They appear of a sensible magnitude to the bare eye, because the retina is affected not only by the rays of light which are emitted directly from

them, but by many thousands more, which falling upon our eye-lids, and upon the aërial particles about us, are reflected into our eyes so strongly, as to excite vibrations not only in those points of the retina where the real images of the stars are formed, but also in other points at some distance round about. This makes us imagine the stars to be much bigger than they would appear, if we saw them only by the few rays which come directly from them, so as to enter our eyes without being intermixed with others. Any one may be sensible of this, by looking at a star of the first magnitude through a long narrow tube; which, though it takes in as much of the sky as would hold a thousand such stars, yet scarce renders *that* one visible.

The more a telescope magnifies, the less is the aperture through which the star is seen; and consequently the fewer rays it admits into the eye. Now, since the stars appear less in a telescope which magnifies 200 times than they do to the bare eye, insomuch that they seem to be only indivisible points, it proves at once that the stars are at immense distances from us, and that they shine by their own proper light. If they shone by borrowed light, they would be as invisible without telescopes as the satellites of Jupiter are; for these satellites appear bigger when viewed with a good telescope than the largest fixed stars do.

A proof that they shine by their own light.

355. The number of stars discoverable, in either hemisphere, by the naked eye, is not above a thousand. This at first may appear incredible, because they seem to be without number: but the deception arises from our looking confusedly upon them, without reducing them into any order: for look but stedfastly upon a pretty large portion of the sky, and count the number of stars in it, and you will be surprised to find them so few. And if one considers how seldom the Moon meets with any stars in her way, although there are as many about her path as in other parts of the heavens, he will soon be convinced that the stars are much thinner sown than he was aware of. The British catalogue, which, besides the stars visible to the bare eye, includes a great number which cannot be seen without the assistance of a telescope, contains no more than 3000, in both hemispheres.[1]

Their number much less than is generally imagined.

[1] If we take a tube, whose length is to its width as 100 to 97, and look at any part of the heavens through a very small hole in one of its extremities, we shall scarcely be able to count more than 100 stars. Now, it may be demonstrated, that

The absurdity of supposing the stars were made only to shine upon us in the night.

356. As we have incomparably more light from the Moon than from all the stars together, it is the greatest absurdity to imagine that the stars were made for no other purpose than to cast a faint light upon the Earth: especially since many more require the assistance of a good telescope to find them out, than are visible without that instrument. Our Sun is surrounded by a system of planets and comets; all which would be invisible from the nearest fixed star. And from what we already know of the immense distance of the stars, the nearest may be computed at 32,000,000,000,000 of miles from us, which is further than a cannon bullet would fly in 7,000,000 of years. Hence it is easy to prove, that the Sun, seen from such a distance, would appear no bigger than a star of the first magnitude. From all this it is highly probable, that each star is a Sun to a system of worlds moving round it, though unseen by us; especially, as the doctrine of a plurality of worlds is rational, and greatly manifests the power, wisdom, and goodness of the great Creator.

Their different magnitudes.

357 The stars, on account of their apparently various magnitudes, have been distributed into several classes or orders. Those which appear largest, are called stars of the first magnitude; the next to them in lustre, stars of the second magnitude; and so on to the sixth, which are the smallest that are visible to the bare eye. This distribution having been made long before the invention of telescopes, the stars which cannot be seen without the assistance of these instruments, are distinguished by the name of telescopic stars.

And division into constellations.

358. The ancients divided the starry sphere into particular constellations, or systems of stars, according as they lay near one another, so as to occupy those spaces which the figures of different sorts of animals or things would take up, if they were there delineated. And those stars which could not be brought into any particular constellation, were called *unformed Stars*.

The use of this division.

359. This division of the stars into different constellations or asterisms, serves to distinguish them from one another, so that any particular star may be readily

this tube takes in exactly a tenth part of the visible hemisphere; and therefore, it follows, that the eye cannot reckon more than 10 × 100, or 1000 stars in one hemisphere.—*Ed.*

found in the heavens by means of a celestial globe; on which the constellations are so delineated, as to put the most remarkable stars into such parts of the figures as are most easily distinguished. The number of the ancient constellations is 48, and upon our present globes about 70. On Senex's globes Bayer's letters are inserted; the first in the Greek alphabet being put to the biggest star in each constellation, the second to the next, and so on: by which means, every star is as easily found as if a name were given to it. Thus, if the star γ in the constellation of the Ram be mentioned, every astronomer knows as well what star is meant, as if it were pointed out to him in the heavens.

The Zodiac.

360. There is also a division of the heavens into three parts. 1, The Zodiac (ζωδιακὸς,) from ζώδιον, zodion, an animal, because most of the constellations in it, which are twelve in number, are the figures of animals: as Aries the ram, Taurus the bull, Gemini the twins, Cancer the crab, Leo the lion, Virgo the virgin, Libra the balance, Scorpio the scorpion, Sagittarius the archer, Capricornus the goat, Aquarius the water-bearer, and Pisces the fishes. The zodiac goes quite round the heavens: it is about 16 degrees broad, so that it takes in the orbits of all the planets, and likewise the orbit of the Moon.[2] Along the middle of this zone or belt, is the ecliptic, or circle which the Earth describes annually, as seen from the Sun; and which the Sun appears to describe, as seen from the Earth. 2, All that region of the heavens, which is on the north side of the zodiac, contains 21 constellations. And, 3, That on the south side, 15.

The manner of dividing it by the ancients.

361 The ancients divided the zodiac into the above 12 constellations or signs, in the following manner. They took a vessel with a small hole in the bottom, and having filled it with water, they suffered the fluid to distil drop by drop into another vessel set beneath to receive it; beginning at the moment when some star rose, and continuing until it rose the next following night. The water fallen down into the receiver, they divided into twelve equal parts; and having two other small vessels in readiness, each of them fit to contain one part, they again poured all the water in-

[2] The zodiac does not comprehend the orbit of PALLAS, which is inclined about 35° to the ecliptic, nor the orbits of the satellites of the Georgium Sidus, which are supposed to move at right angles to the ecliptic.—*Ed.*

to the upper vessel; and observing the rising of some star in the zodiac, they at the same time suffered the water to drop into one of the small vessels; and as soon as it was full, they shifted it, and set an empty one in its place. When each vessel was full, they took notice what star of the zodiac rose; and though this could not be done in one night, yet in many, they observed the rising of twelve stars or points, by which they divided the zodiac into twelve parts.

362. The names of the constellations, and the number of stars observed in each of them by different astronomers, are as follow :—

The Ancient Constellations.

		Ptol.	Tyc.	Hevel.	Flam.	Berl. Cat.
Ursa minor	the Little Bear	8	7	12	24	26
Ursa major	the Great Bear	35	29	73	87	105
Draco	the Dragon	31	32	40	80	87
Cepheus	Cepheus	13	4	51	35	58
Bootes, *Arctophylax*	Plough Driver	23	18	52	54	64
Corona Borealis	the Northern Crown	8	8	8	21	21
Hercules, *Engonasin*	Hercules kneeling	29	28	45	113	119
Lyra	the Harp	10	11	17	21	25
Cygrus, *Gallina*	the Swan	19	18	47	81	83
Cassiopeia	the Lady in her Chair	13	26	37	55	64
Perseus	Perseus	29	29	46	59	73
Auriga	the Waggoner	14	9	40	66	71
Serpentarius, *Ophiuchus*	Serpentarius	29	15	40	74	79
Serpens	the Serpent	18	13	22	64	65
Sagitta	the Arrow	5	5	5	18	18
Aquila, *Vultur*	the Eagle	15	12	23	71	
Antinous	Antinous		3	19		
Delphinus	the Dolphin	10	10	14	18	19
Equulus,	the Horse's Head	4	4	6	10	10
Pegasus, *Equus*	the Flying Horse	20	19	38	89	89
Andromeda	Andromeda	23	23	47	66	73
Triangula	the Triangles	4	4	12	16	17
Aries	the Ram	18	21	27	66	67
Taurus	the Bull	44	43	51	141	143
Gemini	the Twins	25	25	38	85	87
Cancer	the Crab	23	15	29	83	87
Leo	the Lion	35	30	49	95	101
Coma Berenices	Berenice's Hair		14	21	43	48
Virgo	the Virgin	32	33	50	110	117
Libra, *Chelæ*	the Scales	17	10	20	51	55
Scorpio	the Scorpion	24	10	20	35	37
Sagittarius	the Archer	31	14	22	65	73
Capricornus	the Goat	28	28	29	51	54
Aquarius	the Water-bearer	45	41	47	108	119
Pisces	the Fishes	38	36	39	113	115
	the Whale,	22	21	45	97	99
	Orion	38	42	62	78	82
Eridanus, *Fluvius*	Eridanus, *the River*	34	10	27	69	70
Lepus	the Hare	12	13	16	19	20
Canis major	the Great Dog	29	13	21	31	31
Canis minor	the Little Dog	2	2	13	14	18
Argo	the Ship	45	3	4	64	
Hydra	the Hydra	27	19	31	60	62
Crater	the Cup	7	3	10	31	

		Ptol.	Tyc.	Flam.	Brit. Catal.
Corvus	the Crow	7	4	9	10
Centaurus	the Centaur	37		35	
Lupus	the Wolf	19		24	
Ara	the Altar	7		9	
Corona Australis	the Southern Crown	13		12	
Pisces Australis	the Southern Fish	18		24	

The New Southern Constellations.

		Hevel.	Caille.
Columba Noachi	Noah's Dove	10	52
Robur Carolinum	the Royal Oak	12	
Grus	the Crane	13	44
Phœnix	the Phœnix	13	48
Indus	the Indian	12	34
Pavo	the Peacock	14	36
Apus, *Avis Indica*	the Bird of Paradise	11	13
Apis, *Musca*	the Bee or Fly	4	13
Chamæleon	the Chameleon	10	26
Triangulum Australe	the South Triangle	5	13
Piscis volans, *Passer*	the Flying Fish	8	12
Dorado, *Xiphias*	the Sword Fish	6	19
Toucan	the American goose	9	33
Hydrus	the Water Snake	10	24

The following Constellations have been made use of by some Astronomers.

		Caille.
Crux	the Cross	12
Mons Mænalus	the Mountain Mænalus	
Gallus	the Cock	
Nubecula Major	the Greater Cloud	1
Nubecula Minor	the Lesser Cloud	2
Reticulum Rhomboidum	the Rhomboidal Reticulum	15
Cor Caroli	King Charles's heart	

Hevelius's Constellations made out of the unformed Stars.

		Hevel.	Flam.	Berl. Catal.
Lynx	the Lynx	10	44	48
Leo minor	the Little Lion		53	59
Asterion and Chara	the Greyhounds	23	25	36
Cerberus	Cerberus	4		
Vulpecula and Anser	the Fox and Goose	27	35	36
Scutum Sobieski	Sobieski's Shield	7		
Lacerta	the Lizard		16	18
Camelopardalus	the Camelopard	32	58	78
Monoceros	the Unicorn	19	31	31
Sextans	the Sextant	11	41	44

The following new Southern Constellations have been introduced by De la Caille.

		Caille.
Apparatus Sculptoris	the Sculptor's Apparatus	32
Fornax Chymiæ	the Chymist's Furnace	43
Horologium	the Clock	24
Cœlum Sculptorium	the Engraver's Graving Tool	19
Equuleus Pictoris	the Painter's Easel	22
Pyxis Nautica	the Mariner's Compass	14
Antlia Pneumatica	the Air Pump	20
Octans	the Octant	34
Circinus	the Compass	10
Norma	the Rule	15
Telescopium	the Telescope	21
Microscopium	the Microscope	13
Mons Mensæ	the Table Mountain	13

The Milky Way. 363. There is a remarkable track round the heavens, called the *Galaxy* or *Milky Way*, from its peculiar whiteness. It was formerly thought to be owing to a vast number of very small stars therein:[1] but the telescope shews it to be quite otherwise; and therefore its whiteness must be owing to some other cause. This track appears single in some parts, in others double.

Lucid spots. 364. There are several little whitish spots in the heavens, which appear magnified, and more luminous when seen through telescopes; yet without any stars in them. One of these is in Andromeda's girdle, and was first observed A. D. 1612, by Simon Marius: it has some whitish rays near its middle, is liable to several changes, and is sometimes invisible. Another is near the ecliptic, between the head and bow of Sagittarius: it is small, but very luminous. A third is on the back of the Centaur, which is too far south to be seen in Britain. A fourth, of a smaller size, is before Antinous's right foot; having a star in it, which makes it appear more bright. A fifth is in the constellation of Hercules, between the stars ζ and ν, which spot, though but small, is visible to the bare eye if the sky be clear, and the Moon absent.

Cloudy stars. 365. *Cloudy Stars*, or *Nebulæ*, are so called from their misty appearance. They look like dim stars to the naked eye; but through a telescope, they appear broad illuminated parts of the sky; in some of which is one star, in others more. Five of these are mentioned by Ptolemy. 1. One at the extremity of the right hand of Perseus. 2. One in the middle of the Crab. 3. One unformed, near the sting of the Scorpion. 4. The eye of Sagittarius. 5. One in the head of Orion. In the first of these appear more stars through the telescope than in any of the rest, although 21 have been counted in the head of Orion, and above 40 in that of the Crab. Two are visible in the eye of Sagittarius without a telescope, and several more with it. Flamstead observed a cloudy star in the bow of Sagittarius, containing many small stars: and the star *d* above Sagittarius's right shoulder is encompassed with several more. Both Cassini and Flamstead discovered one between the Great and Little Dog, which is very full of stars, visible

[1] The excellent telescopes of Sir William Herschel, indisputably shew, that the milky way is composed of an immense number of telescopic stars.—*Ed.*

only by the telescope. The two whitish spots near the south pole, called the Magellanic Clouds by sailors, which to the bare eye resemble part of the Milky Way, appear through telescopes to be a mixture of small clouds and stars. But the most remarkable of all the cloudy stars, is that in the middle of Orion's Sword, where seven stars (of which three are very close together) seem to shine through a cloud, very lucid near the middle, but faint and ill defined about the edges. It looks like a gap in the sky, through which one may see, as it were, part of a much brighter region. Although most of these spaces are but a few minutes of a degree in breadth, yet, since they are among the fixed stars, they must be spaces larger than what is occupied by our solar system; and in which there seems to be a perpetual uninterrupted day among numberless worlds, which no human art ever can discover.[4]

Magellanic Clouds.

366. Several stars are mentioned by ancient astronomers, which are not now to be found; and others are now visible to the bare eye which are not recorded in the ancient catalogue. Hipparchus observed a new star about 120 years before Christ; but he has not mentioned in what part of the heavens it was seen, although it occasioned his making a catalogue of the stars; which is the most ancient that we have.

Changes in the heavens.

The first new star that we have any good account of, was discovered by Cornelius Gemma on the 8th of November A. D. 1572, in the chair of Cassiopeia. It surpassed Sirius in brightness and magnitude; and was seen for 16 months successively. At first it appeared bigger than Jupiter, to some eyes, by which it was seen at mid-day: afterwards it decayed gradually both in magnitude and lustre, until March 1573, when it became invisible.

New stars.

On the 13th of August 1596, David Fabricius observed the Stella Mira, or wonderful star, in the neck of the whale; which has been since found to appear and disappear periodically, seven times in six years, continuing in the greatest lustre for 15 days together; and is never quite extinguished.

In the year 1600, William Jansenius discovered a changeable star in the neck of the Swan; which, in time, became so

[4] A very full account of nebulæ, and double stars, with drawings of some of the most important, will be found in the supplementary chapter *on the Fixed stars*.—*Ed.*

small as to be thought to disappear entirely, till the years 1657, 1658, and 1659, when it recovered its former lustre and magnitude; but soon decayed, and is now of the smallest size.

In the year 1604, Kepler and several of his friends saw a new star near the heel of the right foot of Serpentarius, so bright and sparkling, that it exceeded any thing they had ever seen before; and took notice that it was every moment changing into some of the colours of the rainbow, except when it was near the horizon, at which time it was generally white. It surpassed Jupiter in magnitude, which was near it all the month of October, but easily distinguished from Jupiter, by the steady light of that planet. It disappeared between October 1605 and the February following, and has not been seen since that time.

In the year 1670, July 15, Hevelius discovered a new star, which in October was so decayed, as to be scarce perceptible. In April following, it regained its lustre, but wholly disappeared in August. In March 1672, it was seen again, but very small; and has not been visible since.

In the year 1686, a new star was discovered by Kirch, which returns periodically in 404 days.

In the year 1672, Cassini saw a star in the neck of the Bull, which he thought was not visible in Tycho's time; nor when Bayer made his figures.

Cannot be

367. Many stars, besides those above mentioned, have been observed to change their magnitudes; and as none of them could ever be perceived to have tails, it is plain they could not be comets; especially as they had no parallax, even when largest and brightest. It would seem that the periodical stars have vast clusters of dark spots, and very slow rotations on their axes; by which means, they must disappear when the side covered with spots is turned towards us. And as for those which break out all of a sudden with such lustre, it is by no means improbable that they are suns whose fuel is almost spent, and again supplied by some of their comets falling upon them, and occasioning an uncommon blaze and splendour for some time; which indeed appears to be the greatest use of the cometary part of any system.[5]

[5] M. Maupertuis, in his dissertation on the figures of the celestial bodies (p. 61-63), is of opinion, that some stars, by their prodigious quick rotations on their axes, may not only assume the figures of oblate spheriods, but that by the great centrifugal force, arising from such rotations, they may become of the figures of mill-stones; or be re-

Some of the stars, particularly Arcturus, have been observed to change their places above a minute of a degree with respect to others. But whether this be owing to any real motion in the stars themselves, must require the observations of many ages to determine. If our solar system changes its place, with regard to absolute space, this must, in process of time, occasion an apparent change in the distances of the stars from each other: and in such a case, the places of the nearest stars to us being more affected than those which are very remote, their relative positions must seem to alter, though the stars themselves were really immoveable.[6] On the other hand, if our own system be at rest, and any of the stars in real motion, this must vary their positions; and the more so, the nearer they are to us, or swifter their motions are; or the more proper the direction of their motion is for our perception.

Some stars change their places.

368. The obliquity of the ecliptic to the equinoctial is found at present to be above the third part of a degree less than Ptolemy found it. And most of the observers after him, found it to decrease gradually down to Tycho's time. If it be objected, that we cannot depend on the observations of the ancients, because of the incorrectness of their instruments; we have to answer, that both Tycho and Flamstead are allowed to have been very good observers; and yet we find that Flamstead makes this obliquity 2½ minutes of a degree less than Tycho did, about 100 years before him: and as Ptolemy was 1324 years before Tycho, so the gradual decrease answers nearly to the difference of time between these three astronomers. If we consider, that the Earth is not a perfect sphere, but an oblate

The ecliptic less oblique now to the equator than formerly.

duced to flat circular planes, so thin as to be quite invisible when their edges are turned towards us; as Saturn's ring is in such positions. But when any eccentric planets or comets go round any flat star, in orbits much inclined to its equator, the attraction of the planets or comets in their perihelions, must alter the inclination of the axis of that star; on which account, it will appear more or less large and luminous, as its broad side is more or less turned towards us. And thus he imagines we may account for the apparent changes of magnitude and lustre in those stars, and likewise for their appearing and disappearing.

[6] This change in the relative positions of the fixed stars has been detected by Sir William Herschel, who has ingeniously attempted to deduce, from the nature of these changes, the velocity of our system, and the direction in which it moves. See the supplementary chapter *On the Fixed Stars*.—*Ed.*

spheroid, having its axis shorter than its equatoreal diameter; and that the Sun and Moon are constantly acting obliquely upon the greater quantity of matter about the equator, pulling it, as it were, towards a nearer and nearer coincidence with the ecliptic; it will not appear improbable, that these actions should gradually diminish the angle between those planes. Nor is it less probable that the mutual attraction of all the planets should have a tendency to bring their orbits to a coincidence: but this change is too small to become sensible in many ages.[7]

CHAP. XXI.

OF THE DIVISION OF TIME—A PERPETUAL TABLE OF NEW MOONS—THE TIMES OF THE BIRTH AND DEATH OF CHRIST—A TABLE OF REMARKABLE ERAS OR EVENTS.

369. The parts of time are Seconds, Minutes, Hours, Days, Years, Cycles, Ages, and Periods.

A year. 370. The original standard, or integral measure of time, is a year; which is determined by the revolution of some celestial body in its orbit, viz. the Sun or Moon.

Tropical year. 371. The time measured by the Sun's revolution in the ecliptic, from any equinox or solstice, to the same again, is called the Solar or Tropical Year, which contains 365 days 5 hours 48 minutes 57 seconds; and is the only proper or natural year, because it always keeps the same seasons to the same months.

Sydereal year. 372. The quantity of time measured by the Sun's revolution, as from any fixed star to the same star again, is called the Sydereal Year; which contains 365 days 6 hours 9 minutes 14½ seconds; and is 20 minutes 17½ seconds longer than the true solar year.

Lunar year. 373. The time measured by twelve revolutions of the Moon, from the Sun to the Sun again, is called the Lunar Year; it contains 354 days, 8 hours, 48 minutes, 36 seconds; and is therefore 10 days, 21 hours, 0 minutes, 21 seconds, shorter than the solar year. This is the foundation of the epact.

[7] See the Supplementary chapter on the Obliquity of the Ecliptic.

374. The Civil Year is that which is in common use among the different nations of the world; of which, some reckon by the lunar, but most by the solar. The civil solar year contains 365 days, for three years running, which are called Common Years; and then comes in what is called the Bissextile or Leap-year, which contains 366 days. This is also called the Julian Year, on account of Julius Cæsar, who appointed the intercalary day every fourth year, thinking thereby to make the civil and solar year keep pace together. And this day, being added to the 23d of February, which in the Roman calendar was the sixth of the calends of March, that sixth day was twice reckoned, or the 23d and 24th were reckoned as one day; and was called *Bis sextus dies*, and thence came the name Bissextile for that year. But in our common almanacks, this day is added at the end of February.

Civil year.

375. The Civil Lunar Year is also common or intercalary. The common year consists of 12 lunations, which contain 354 days; at the end of which, the year begins again. The Intercalary, or Embolimic year, is that wherein a month was added, to adjust the lunar year to the solar. This method was used by the Jews, who kept their account by the lunar motions. But by intercalating no more than a month of 30 days, which they called *Ve-Adar*, every third year they fell $3\frac{3}{4}$ days short of the solar year in that time.

Lunar year.

376. The Romans also used the lunar embolimic year at first, as it was settled by Romulus their first king, who made it to consist only of ten months or lunations; which fell 61 days short of the solar year, and so their year became quite vague and unfixed; for which reason they were forced to have a table published by the high-priest, to inform them when the spring and other seasons began. But Julius Cæsar, as already mentioned, § 374, taking this troublesome affair into consideration, reformed the calendar, by making the year to consist of 365 days, 6 hours.

Roman year.

377. The year thus settled, is what was used in Britain till A. D. 1752: but as it is somewhat more than 11 minutes longer than the solar tropical year, the times of the equinoxes go backward, and fall earlier by one day in about 130 years. In the time of the Nicene Council (A. D. 325), which was 1439 years ago, the vernal equinox fell on the 21st of March: and if we divide 1444

The original of the Gregorian, or new style.

by 180, it will quote 11, which is the number of days the equinox has fallen back since the council of Nice. This causing great disturbances, by unfixing the times of the celebration of Easter, and consequently of all the other moveable feasts, pope Gregory the XIII, in the year 1582, ordered ten days to be at once struck out of that year; and the next day after the 4th of October, was called the 15th. By this means the vernal equinox was restored to the 21st of March; and it was endeavoured, by the omission of three intercalary days in 400 years, to make the civil or political year keep pace with the solar for the time to come. This new form of the year is called the Gregorian account, or New Style; which is received in all countries where the pope's authority is acknowledged, and ought to be received in all places where truth is regarded

Months. 378. The principal division of the year is into months, which are of two sorts, namely, Astronomical and Civil. The astronomical month is the time in which the Moon runs through the zodiac, and is either periodical or synodical. The periodical month is the time spent by the Moon in making one complete revolution from any point of the zodiac to the same again; which is $27^d\ 7^h\ 43^m$. The synodical month, called a lunation, is the time contained between the Moon's parting with the Sun at a conjunction, and returning to him again; which is $29^d\ 12^h\ 44^m$. The civil months are those which are framed for the uses of civil life; and are different as to their names, number of days, and times of beginning, in several different countries. The first month of the Jewish year fell, according to the Moon, in our August and September, old style; the second in September and October; and so on. The first month of the Egyptian year began on the 29th of our August. The first month of the Arabic and Turkish year began the 16th of July. The first month of the Grecian year fell, according to the Moon, in June and July, the second in July and August, and so on, as in the following table..

379. A month is divided into four parts called weeks, and a week into seven parts called days; so that in a Julian year there are 13 such months, or 52 weeks, and one day over. The Gentiles gave the names of the Sun, Moon, and Planets, to the days of the week. To the first, the name of the Sun; to the second, of the Moon; to the third, of Mars; to the fourth, of Mercury; to the fifth, of Jupiter; to the sixth, of Venus; and to the seventh, of Saturn.

No.	The Jewish year.	Days.
1	Tisri... ....Aug. —Sept.	30
2	Marchesvan....Sept. —Oct.	29
3	Casleau .... Oct. —Nov.	30
4	Tebeth ....Nov. —Dec.	29
5	Shebat.... . ...Dec. —Jan.	30
6	Adar . ... Jan —Feb.	29
7	Nisan or Abib.Feb. —Mar.	30
8	Jiar.... ....Mar. —Apr.	29
9	Sivan ....Apr. —May	30
10	Tamuz ....May —June	29
11	Ab ....June —July	30
12	Elul ....July — Aug.	29
	Days in the year	354

In the Embolimic year after Adar, they added a month called Ve-Adar, of 30 days.

No.	The Egyptian year.	Days.
1	Thoth............August....29	30
2	Paophi...........September.28	30
3	Athir............October....28	30
4	Chojac...........November.27	30
5	Tybi.............December.27	30
6	Mechir ....January ...26	30
7	Phamenoth......February..25	30
8	Parmuthi........March.....27	30
9	Pachon... ......April 26	30
10	Payni ....May 26	30
11	Epiphi ....June........25	30
12	Mesori.... .....July........25	30
	Epagomenæ, or days added....	5
	Days in the year................	365

No.	The Arabic & Turkish year.	Days.
1	Muharram ....July........16	30
2	Saphar ....August....15	29
3	Rabia I..........September.13	30
4	Rabia II ....October....13	29
5	Jomada I........November.11	30
6	Jomada II......December.11	29
7	Rajab .... January.....9	30
8	Shasban..........February ...8	29
9	Ramadam.......March.......9	30
10	Shawal... ...... April 8	29
11	Dulhaadah ......May 7	30
12	Dulheggia.......June.........5	29
	Days in the year................	354

The Arabians add 11 days at the end of every year, which keeps the same months to the same seasons.

No.	The ancient Grecian year.	Days.
1	Hecatombæon...June—July	30
2	Metagitnion ...July —Aug.	29
3	Boedromion ...Aug.—Sept.	30
4	Pyanepsion.....Sept.—Oct.	29
5	Maimacterion ..Oct. —Nov.	30
6	Posideon.. .....Nov.—Dec.	29
7	Gamelion.......Dec.—Jan.	30
8	Anthesterion...Jan.—Feb.	29
9	Elaphebolion...Feb.—Mar.	30
10	Munichion .....Mar.—Apr.	29
11	Thargelion......Apr.—May	30
12	Schirrophorion.May—June	29
	Days in the year................	354

380. A day is either natural or artificial. The natural day contains 24 hours; the artificial, the time from sun-rise to sun-set. The natural day is either astronomical or civil. The astronomical day begins at noon, because the increase and decrease of days terminated by the horizon are very unequal among themselves; which inequality is likewise augmented by the inconstancy of the horizontal refractions, § 186; and therefore the astronomer takes the meridian

Days.

for the limit of diurnal revolutions; reckoning noon, that is, the instant when the Sun's centre is on the meridian, for the beginning of the day. The British, French, Dutch, Germans, Spaniards, Portuguese, and Egyptians, begin the civil day at midnight: the ancient Greeks, Jews, Bohemians, Silesians, with the modern Italians, and Chinese, begin it at sun-setting: and the ancient Babylonians, Persians, Syrians, with the modern Greeks, at sun-rising.

Hours. 381. An hour is a certain determinate part of the day, and is either equal or unequal. An equal hour is the 24th part of a mean natural day, as shewn by well regulated clocks and watches; but these hours are not quite equal, as measured by the returns of the Sun to the meridian, because of the obliquity of the ecliptic, and the Sun's unequal motion in his orbit, § 224–245. Unequal hours are those by which the artificial day is divided into 12 parts, and the night into as many.

Minutes, seconds, thirds, and scruples. 382. An hour is divided into 60 equal parts called minutes, a minute into 60 equal parts called seconds, and these again into 60 equal parts called thirds. The Jews, Chaldeans, and Arabians, divide the hour into 1080 equal parts called scruples; which number contains 18 times 60, so that one minute contains 18 scruples.

Cycles of the Sun, Moon, and indiction. 383. A cycle is a perpetual round, or circulation, of the same parts of time of any sort. The cycle of the Sun is a revolution of 28 years, in which time the days of the months return again to the same days of the week; the Sun's place to the same signs and degrees of the ecliptic on the same months and days, so as not to differ one degree in 100 years; and the leap-years begin the same course over again with respect to the days of the week on which the days of the months fall. The cycle of the Moon, commonly called the golden number, is a revolution of 19 years; in which time, the conjunctions, oppositions, and other aspects of the Moon, are within an hour and a half of being the same as they were on the same days of the months 19 years before. The indiction is a revolution of 15 years, used only by the Romans for indicating the times of certain payments made by the subjects to the republic: it was established by Constantine, A. D. 312.

384. The year of our Saviour's birth, according to the vulgar era, was the 9th year of the solar cycle; the first year of the lunar cycle; and the 312th year after his birth was the first year of the Roman indiction. Therefore, to find the year of the solar cycle, add 9 to any given year of Christ, and divide the sum by 28, the quotient is the number of cycles elapsed since his birth, and the remainder is the cycle for the given year: if nothing remains, the cycle is 28. To find the lunar cycle, add 1 to the given year of Christ, and divide the sum by 19; the quotient is the number of cycles elapsed in the interval, and the remainder is the cycle for the given year: if nothing remains, the cycle is 19. Lastly, subtract 312 from the given year of Christ, and divide the remainder by 15; and what remains after this division is the indiction for the given year: if nothing remains, the indiction is 15.

To find the years of these cycles.

385. Although the above deficiency in the lunar cycle of an hour and half every 19 years, be but small, yet in time it becomes so sensible as to make a whole natural day in 310 years. So that, although this cycle be of use, when the golden numbers are rightly placed against the days of the months in the calendar, as in our common prayer-books, for finding the days of the mean conjunctions or oppositions of the Sun and Moon, and consequently the time of Easter; it will only serve for 310 years, old style. For, as the new and full moons anticipate a day in that time, the golden numbers ought to be placed one day earlier in the calendar for the next 310 years to come. These numbers were rightly placed against the days of new moon in the calendar by the council of Nice, A. D. 325; but the anticipation, which has been neglected ever since, is now grown almost into 5 days; and therefore all the golden numbers ought now to be placed 5 days higher in the calendar for the old style than they were at the time of the said council; or six days lower for the new style, because at present it differs 11 days from the old.

The deficiency of the lunar cycle, and consequence thereof.

386. In the annexed table, the golden numbers under the months stand against the days of new moon in the left-hand column, for the new style; adapted chiefly to the second year after leap-year, as being the nearest mean for all the four; and will serve till

How to find the day of the new moon by the golden number.

the year 1900. Therefore, to find the day of new moon in any month of a given year till that time, look for the golden number of that year under the desired month, and against it, you have the day of new moon in the left-hand column.

Days.	Jan.	Feb.	March	April	May	June	July.	August	Sept.	Oct.	Nov.	Dec.
1	9		9	17	17	6				11		19
2		17			6	14	14	3	11		19	
3	17	6	17	6			3	11		19	8	8
4	6		6	14	14	3			19	8		16
5		14			3	11	11	19	8		16	
6	14	3	14	3			19			16	5	5
7	3		3	11	11	19		8	16			13
8		11			19	8	8	16	5	5	13	
9	11	19	11	19						13		2
10			19	8	8	16	16	5	13		2	10
11	19	8					5	13	2	2	10	
12	8	16	8	16	16	5				10		18
13					5	13	13	2	10		18	7
14	16	5	16	5			2	10	18	18	7	
15	5		5	13	13	2				7		15
16		13			2	10	10	18	7		15	
17	13	2	13	2			18	7		15	4	4
18	2		2	10	10	18			15			12
19		10			18	7	7	15	4	4	12	
20	10	18	10	18			15			12	1	1
21	18		18	7	7	15		4	12			9
22		7			15	4	4	12	1	1	9	
23	7	15	7	15			12			9	17	17
24			15	4	4	12		1	9			6
25	15	4			12		1	9	17	17	6	
26	4		4	12		1				6		14
27		12		1	1	9	9	17	6		14	
28	12	1	12		9		17	6	14	14	3	3
29	1		1	9		17				3		11
30					17	6	6	14	3		11	
31	9		9				14	3		11		19

Thus, suppose it were required to find the day of new moon in September 1757; the golden number for that year is 10, which

I look for under September, and right against it in the left-hand column I find 13, which is the day of new moon in that month.

N. B. If all the golden numbers, except 17 and 6, were set one day lower in the table, it would serve from the beginning of the year 1900 till the end of the year 2199. The first table after this chapter shews the golden number for 4000 years after the birth of Christ; by looking for the even hundreds of any given year at the left hand, and for the rest to make up that year at the head of the table; and where the columns meet, you have the golden number (which is the same both in the old and new style) for the given year. Thus, suppose the golden number was wanted for the year 1757; I look for 1700 at the left hand of the table, and for 57 at the top of it; then guiding my eye downward from 57 to over against 1700, I find 10, which is the golden number for that year.

387. But because the lunar cycle of 19 years sometimes includes five leap-years, and at other times only four, this table will sometimes vary a day from the truth in leap-years after February. And it is impossible to have one more correct, unless we extend it to four times 19, or 76 years; in which there are 19 leap-years without a remainder. But even then to have it of perpetual use, it must be adapted to the old style; because in every centurial year not divisible by 4, the regular course of leap-years is interrupted in the new; as will be the case in the year 1800. Therefore, upon the regular old style plan, I have computed the following table of the mean times of all the new moons to the nearest hour for 76 years; beginning with the year of Christ 1724, and ending with the year 1800.

A perpetual table of the time of new moon to the nearest hour, for the old style.

This table may be made perpetual, by deducting 6 hours from the time of new moon in any given year and month from 1724 to 1800, in order to have the mean time of new moon in any year and month 76 years afterwards; or deducting 12 hours for 152 years; 18 hours for 228 years; and 24 hours for 304 years: because in that time the changes of the Moon anticipate almost a complete natural day. And if the like number of hours be added for so many years past, we shall have the mean time of any new moon already elapsed. Suppose, for example, the mean time of change was required for January 1802, deduct 76 years, and there remains 1726,

against which, in the following table, under January, I find the time of new moon was on the 21st day, at 11 in the evening: from which take 6 hours, and there remains the 21st day, at 5 in the evening, for the mean time of change in January 1802. Or, if the time be required for May, A. D. 1701, add 76 years, and it makes 1777, which I look for in the table, and against it under May, I find that the new moon in that year falls on the 25th day, at 9 in the evening; to which add 6 hours, and it gives the 26th day, at 3 in the morning, for the time of new moon in May, A. D. 1701. By this addition for time past, or subtraction for time to come, the table will not vary 24 hours from the truth in less than 14,592 years. And if, instead of 6 hours for every 76 years, we add or subtract only 5 hours 52 minutes, it will not vary a day in 10 millions of years.

Although this table is calculated for 76 years only, and according to the old style, yet by means of two easy equations, it may be made to answer as exactly to the new style, for any time to come. Thus, because the year 1724 in this table is the first year of the cycle for which it is made; if, from any year of Christ after 1800, you subtract 1723, and divide the overplus by 76, the quotient will shew how many entire cycles of 76 years are elapsed since the beginning of the cycle here provided for; and the remainder will shew the year of the current cycle answering to the given year of Christ. Hence, if the remainder be 0, you must, instead thereof, put 76, and lessen the quotient by unity.

Then, look in the left-hand column of the table for the number in your remainder, and against it you will find the times of all the mean new moons in that year of the present cycle. And whereas, in 76 Julian years, the Moon anticipates 5 hours 52 minutes, if therefore these 5 hours 52 minutes be multiplied by the above-found quotient; that is, by the number of entire cycles past; the product subtracted from the times in the table will leave the corrected times of the new moons to the old style; which may be reduced to the new style thus:—

Divide the number of entire hundreds in the given year of Christ by 4, multiply this quotient by 3, to the product add the remainder, and from their sum subtract 2: this last remainder denotes the number of days to be added to the times above corrected, in order to reduce them to the new style. The reason of this is, that every 400 years of the new style gains 3

days upon the old style; one of which it gains in each of the centurial years succeeding that which is exactly divisible by 4 without a remainder; but then, when you have found the days so gained, 2 must be subtracted from their number, on account of the rectifications made in the calendar by the council of Nice, and since by Pope Gregory. It must also be observed, that the additional days found as above directed, do not take place in the centurial years which are not multiples of 4 till February 29th, old style, for on that day begins the difference between the styles; till which day, therefore, those that were added in the preceding years must be used. The following example will make this accommodation plain.

Required the mean time of New Moon in June, A. D. 1909, N. S.

From 1909 take 1723 years, and there remains..........	186
Which divided by 76, gives the quotient 2, and the remainder	34
Then, against 34 in the Table is June....................	5d 8h 0m afternoon
And 5h 52m multiplied by 2, make to be subtracted.......	11h 44m
Remains the mean time, according to the old style, June...	5d 9h 16m
Entire hundreds in 1909 are 19, which divide by 4, quotes	4
And leaves a remainder of......................................	3
Which quotient multiplied by 3, makes 12, and the remainder added, makes..	15
From which subtract 2, and there remains....................	13
Which number of days added to the above time, old style, gives June..	18d 9h 16m morn. N. S.

So the mean time of new moon in June 1909, new style, is the 18th day, at 16 minutes past 9 in the morning.

If 11 days be added to the time of any new moon in this table, it will give the time thereof, according to the new style, till the year 1800. And, if 14 days 18 hours 22 minutes, be added to the mean time of new moon in either style, it will give the mean time of the next full moon, according to that style.

A Table shewing the Times of all the mean Changes of the Moon, to the nearest Hour, through four Lunar Periods, or 76 Years. M *signifies Morning,* A *Afternoon.*

Yrs. of the Cyc.	A. D.	January D.	January H.	February D.	February H.	March D.	March H.	April D.	April H.	May D.	May H.	June D.	June H.
1	1724	14	5 A	13	5 M	13	6 A	12	7 M	11	8 A	10	8 M
2	1725	3	2 M	1	2 A	3	3 M	1	4 A	1 / 30	4 M / 5 A	29	6 M
3	1726	21	11 A	20	11 M	21	12 A	20	1 A	20	1 M	18	2 A
4	1727	11	8 M	9	9 A	11	9 M	9	10 A	9	11 M	7	12 A
5	1728	30	6 M	28	7 A	29	7 M	27	8 A	27	8 M	25	9 A
6	1729	18	2 A	17	3 M	18	4 A	17	4 M	16	5 A	15	6 M
7	1730	7	11 A	6	0 A	8	1 M	6	1 A	6	2 M	4	3 A
8	1731	26	9 A	25	10 M	26	10 A	25	11 M	24	11 A	23	0 A
9	1732	16	5 M	14	6 A	15	7 M	13	8 A	13	8 M	11	9 A
10	1733	4	2 A	3	3 M	4	4 A	3	4 M	2	5 A	1 / 30	6 M / 7 A
11	1734	23	0 A	22	1 M	23	1 A	22	2 M	21	2 A	20	3 M
12	1735	12	9 A	11	9 M	12	10 A	11	11 M	10	11 A	9	0 A
13	1736	2 / 31	5 M / 6 A	—	—	1 / 30	7 M / 8 A	29	9 M	28	9 A	27	10 M
14	1737	20	3 M	18	4 A	20	4 M	18	5 A	18	5 M	16	6 A
15	1738	9	11 M	7	12 A	9	1 A	8	1 M	7	2 A	6	3 A
16	1739	28	9 M	26	10 A	28	1 M	26	12 A	26	0 A	25	1 M
17	1740	17	6 A	16	7 M	16	8 A	15	9 M	14	9 A	13	10 M
18	1741	6	3 M	4	4 A	6	4 M	4	5 A	4	5 M	2	6 A
19	1742	24	12 A	23	1 A	25	2 M	23	3 A	23	3 M	21	4 A
20	1743	14	9 M	12	10 A	14	11 M	12	12 A	12	0 A	11	1 M
21	1744	3	6 A	2	7 M	2	8 A	1 / 30	9 M / 9 A	30	10 M	28	11 A
22	1745	21	4 A	20	5 M	21	5 A	20	6 M	19	6 A	18	7 M
23	1746	10	12 A	9	1 A	11	2 M	9	3 A	9	3 M	7	4 A
24	1747	29	10 A	28	11 M	29	11 A	28	0 A	27	12 A	26	1 A
25	1748	19	6 M	17	7 A	18	8 M	16	9 A	16	9 M	14	10 A
26	1749	7	3 A	6	4 M	7	5 A	6	6 M	5	6 A	4	7 M
27	1750	26	1 A	25	2 M	26	3 A	25	4 M	24	4 A	23	5 M
28	1751	15	10 A	14	11 M	15	11 A	14	0 A	13	12 A	12	1 A
29	1752	5	6 M	3	7 A	4	8 M	2	9 A	2 / 31*	9 M / 10 A	30	11 M
30	1753	23	4 M	21	5 A	23	6 M	21	7 A	21	7 M	19	8 A
31	1754	12	1 A	11	2 M	12	3 A	11	4 M	10	4 A	9	5 M
32	1755	1 / 31	10 A / 11 M	—	—	1 / 31	11 A / 0 A	29	12 A	29	1 A	28	2 M
33	1756	20	7 A	19	8 M	19	9 A	18	9 M	17	10 A	16	11 M
34	1757	9	4 M	7	5 A	9	6 M	7	7 A	7	7 M	6	8 A
35	1758	28	2 M	26	3 A	28	3 M	26	4 A	26	4 M	24	5 A
36	1759	17	10 M	15	11 A	17	0 A	16	1 M	15	1 A	14	2 M
37	1760	6	7 A	5	8 M	5	9 A	4	10 M	3	10 A	2	11 M

A Table of the mean New Moons, &c.

Yrs. of the Cyc.	A. D.	July D.	July H.	August D.	August H.	Sept. D.	Sept. H.	October D.	October H.	Nov. D.	Nov. H.	Dec. D.	Dec. H.
1	1724	9	9 A	8	10 M	6	10 A	6	11 M	4	12 A	4	1 A
2	1725	28	7 A	27	8 M	25	8 A	25	9 M	23	10 A	23	11 M
3	1726	18	3 M	16	4 A	15	5 M	14	5 A	13	6 M	12	7 A
4	1727	7	0 A	6	1 M	4	1 A	4	2 M	2	3 A	2 31	4 M 5 A
5	1728	25	10 M	23	11 A	22	11 M	21	12 A	20	1 A	20	2 M
6	1729	14	7 A	12	7 M	11	8 A	11	9 M	9	10 A	9	11 M
7	1730	4	3 M	2	4 A	2 30	5 M 6 A	30	7 M	28	8 A	28	9 M
8	1731	23	1 M	21	2 A	20	2 M	19	3 A	18	4 M	17	5 A
9	1732	11	10 M	9	11 A	8	11 M	7	12 A	6	1 A	6	2 M
10	1733	30	8 M	28	8 A	27	9 M	26	10 A	25	11 M	24	11 A
11	1734	19	4 A	18	5 M	16	5 A	16	6 M	14	7 A	14	8 M
12	1735	9	4 M	7	2 A	6	2 M	5	3 A	4	4 M	3	5 A
13	1736	26	11 A	2[illegible]	0 A	23	12 A	23	1 A	22	2 M	21	3 A
14	1737	16	7 M	14	8 A	13	8 M	12	9 A	11	10 M	10	11 A
15	1738	5	4 A	4	5 M	2	5 A	2 31	6 M 7 A	30	8 M	29	8 A
16	1739	24	2 A	23	3 M	21	0 A	21	4 M	19	5 A	19	6 M
17	1740	12	11 A	11	0 A	9	12 A	9	1 A	8	2 M	7	3 A
18	1741	2 31	7 M 7 A	30	8 M	28	9 A	28	10 M	26	11 A	26	11 M
19	1742	21	5 M	19	6 A	18	6 M	17	7 A	16	8 M	15	9 A
20	1743	10	2 A	9	3 M	7	3 A	7	4 M	5	5 A	5	6 M
21	1744	28	0 A	26	12 A	25	1 A	25	2 M	23	3 A	23	3 M
22	1745	17	8 A	16	8 M	14	9 A	14	10 M	12	11 A	12	0 A
23	1746	7	5 M	5	6 A	4	6 M	3	7 A	2	8 M	1 31	9 A 10 M
24	1747	26	2 M	24	3 A	23	3 M	22	4 A	21	5 M	20	6 A
25	1748	14	11 M	12	12 A	11	0 A	11	1 M	9	2 A	9	3 M
26	1749	3	8 A	2 31	9 M 9 A	30	10 M	29	11 A	8	0 A	27	12 A
27	1750	22	6 A	21	7 M	19	7 A	19	8 M	17	9 A	17	10 M
28	1751	12	2 M	10	3 A	9	3 M	8	4 A	7	5 M	6	6 A
29	1752	29	12 A	28	0 A	27	1 M	26	2 A	25	3 M	24	3 A
30	1753	19	9 M	17	10 A	16	10 M	15	11 A	14	0 A	14	1 M
31	1754	8	6 A	7	7 M	5	7 A	5	8 M	3	9 A	3	10 M
32	1755	27	3 A	25	3 M	24	4 A	24	5 M	22	6 A	22	6 M
33	1756	15	12 A	14	1 A	13	1 M	12	2 A	11	3 M	10	4 A
34	1757	5	9 M	3	10 A	2	10 M	1 31	11 A 0 A	30	1 M	29	1 A
35	1758	24	6 M	22	7 A	21	7 M	20	8 A	19	9 M	18	10 A
36	1759	13	3 A	12	2 M	10	4 A	10	5 M	8	6 A	8	7 M
37	1760	1 31	12 A 1 A	30	1 M	28	2 A	28	3 M	26	4 A	26	4 M

A Table of mean New Moons concluded.

Yrs. of the Cyc.	A. D.	January D.	H.	February D.	H.	March D.	H.	April D.	H.	May D.	H.	June D.	H.
38	1761	24	5 A	23	6 M	24	7 A	23	8 M	22	9 A	21	10 M
39	1762	14	2 M	12	3 A	14	3 M	12	4 A	12	4 M	10	5 A
40	1763	3	11 M	1	12 A	3	0 A	2	1 M	1 31	1 A 2 M	29	3 A
41	1764	22	8 M	20	9 A	21	10 M	19	11 A	19	11 M	17	12 A
42	1765	10	5 A	9	6 M	10	6 A	9	7 M	8	7 A	7	8 M
43	1766	29	2 A	28	3 M	29	4 A	28	5 M	27	5 A	26	6 M
44	1767	18	11 A	17	0 A	19	1 M	17	2 A	17	2 M	15	3 A
45	1768	8	8 M	6	9 A	7	10 M	5	11 A	5	11 M	3	12 A
46	1769	26	6 M	24	7 A	26	7 M	24	8 A	24	8 M	22	9 A
47	1770	15	2 A	14	3 M	15	4 A	14	5 M	13	5 A	12	4 M
48	1771	4	11 M	3	0 A	5	1 M	3	2 A	3	2 M	1	3 A
49	1772	23	9 A	22	10 M	22	10 A	21	11 M	20	11 A	19	0 A
50	1773	12	5 M	10	6 A	12	7 M	10	8 A	10	8 M	8	9 A
51	1774	1 31	2 A 3 M	—	—	1 31	4 A 5 M	29	5 A	29	6 M	27	7 A
52	1775	20	0 A	19	1 M	20	2 A	19	3 M	18	3 A	17	4 M
53	1776	9	9 A	8	10 M	8	10 A	7	11 M	6	12 A	5	0 A
54	1777	27	6 A	26	7 M	27	8 A	26	9 M	25	9 A	24	10 M
55	1778	17	3 M	15	4 A	17	5 M	15	6 A	15	6 M	13	7 A
56	1779	6	0 A	5	1 M	6	2 A	5	3 M	4	3 A	3	4 M
57	1780	25	10 M	23	11 A	24	11 M	22	12 A	22	0 A	21	1 M
58	1781	13	6 A	12	7 M	13	8 A	12	9 M	11	9 A	10	10 M
59	1782	3	3 M	1	4 A	3	5 M	1	6 A	1 30	6 M 7 A	29	8 M
60	1783	22	1 M	20	2 A	22	2 M	20	3 A	20	3 M	18	4 A
61	1784	11	9 M	9	10 A	10	11 M	8	12 A	8	0 A	7	1 M
62	1785	29	7 M	27	8 A	29	9 M	27	10 A	27	10 M	25	11 A
63	1786	18	4 A	17	5 M	18	5 A	17	6 M	16	6 A	15	7 M
64	1787	7	12 A	6	1 A	8	2 M	6	3 A	6	3 M	4	4 A
65	1788	26	10 A	25	11 M	25	12 A	24	1 A	24	1 M	22	2 A
66	1789	15	7 M	13	8 A	15	9 M	13	10 A	13	10 M	11	11 A
67	1790	4	4 M	3	5 M	4	5 A	3	6 M	2	6 A	1 30	7 M 8 A
68	1791	23	1 A	22	2 M	23	3 A	22	4 M	21	4 A	20	5 M
69	1792	12	10 A	11	11 M	11	12 A	10	1 A	10	1 M	8	2 A
70	1793	1 30	7 M 8 A	—	—	1 30	9 M 10 A	29	10 M	28	11 A	27	0 A
71	1794	20	5 M	18	6 A	20	6 M	18	7 A	18	7 M	16	8 A
72	1795	9	1 A	8	2 M	9	3 A	8	4 M	7	4 A	6	5 M
73	1796	28	11 M	26	12 A	27	0 A	26	1 M	25	1 A	24	2 M
74	1797	16	7 A	15	8 M	16	9 A	15	10 M	14	10 A	13	11 M
75	1798	6	4 M	4	5 A	6	6 M	4	7 A	4	7 M	2	8 A
76	1799	25	2 M	23	3 A	25	4 M	23	5 A	23	5 M	21	6 A
1	1800	14	11 M	12	12 A	13	0 A	12	1 M	11	1 A	10	2 M

The year 1800 begins a new Cycle.

A Table of mean New Moons conclud...

Y. of Cyc.	A. D.	July D.	July H.	August D.	August H.	Sept. D.	Sept. H.	October D.	October H.	Nov. D.	Nov. H.	Dec. D.	Dec. H.
38	1761	20	10 A	19	11 M	17	11 A	17	0 A	16	1 M	15	2 A
39	1762	10	6 M	8	7 A	6	7 M	6	8 A	5	9 M	4	10 A
40	1763	29	4 M	27	4 A	26	5 M	25	6 A	24	7 M	23	7 A
41	1764	17	1 A	16	2 M	14	2 A	14	3 M	12	4 A	12	5 M
42	1765	6	9 A	5	10 M	3	10 A	3	11 M	1	12 A	1 31	1 A 1 M
43	1766	25	7 A	24	8 M	22	8 A	22	9 M	20	10 A	20	11 M
44	1767	15	4 M	13	5 A	12	6 M	11	6 A	10	7 M	9	8 A
45	1768	3	1 A	2 31	2 M 2 A	30	3 M	29	4 A	28	5 M	27	5 A
46	1769	22	10 M	20	11 A	19	1 M	18	12 A	17	1 A	17	2 M
47	1770	11	7 A	10	8 M	8	8 A	8	9 M	6	10 A	6	11 M
48	1771	1 30	1 M 5 A	29	5 M	27	6 A	27	7 M	25	8 A	25	9 M
49	1772	19	1 M	17	2 A	16	2 M	15	3 A	11	4 M	13	5 A
50	1773	8	9 M	6	10 A	5	11 M	4	12 A	3	1 A	3	2 M
51	1774	27	8 M	25	8 A	24	9 M	23	10 A	22	11 M	21	11 A
52	1775	16	[illegible] A	15	6 M	15	6 A	13	7 M	11	8 A	11	9 M
53	1776	5	1 M	3	2 A	2	2 M	1 31	3 A 1 M	29	5 A	9	5 M
54	1777	23	11 A	22	0 A	20	12 A	20	1 A	19	2 M	18	3 A
55	1778	13	8 M	11	9 A	10	9 M	9	10 A	8	11 M	7	12 A
56	1779	2	5 A	1 30	6 M 6 A	29	7 M	28	8 A	27	9 M	26	9 A
57	1780	20	2 A	19	3 M	17	3 A	17	4 M	15	5 A	15	6 M
58	1781	9	11 A	8	0 A	6	12 A	6	1 A	5	2 M	4	3 A
59	1782	28	9 A	27	9 M	25	10 A	25	11 M	23	12 A	23	0 A
60	1783	18	5 M	16	6 A	15	6 M	14	7 A	13	8 M	12	9 A
61	1784	6	2 A	5	3 M	3	3 A	3	4 M	1	5 A	1 30	6 M 6 A
62	1785	25	0 A	24	1 M	22	1 A	22	2 M	20	3 A	20	3 M
63•	1786	14	8 A	13	9 M	11	9 A	11	10 M	9	11 A	9	0 A
64	1787	4	5 M	2	6 A	1 30	6 M 7 A	30	8 M	28	9 A	28	9 M
65	1788	22	3 M	20	4 A	19	4 M	18	5 A	17	6 M	16	7 A
66	1789	11	0 A	10	1 M	8	1 A	8	2 M	6	3 A	6	4 M
67	1790	30	9 M	28	9 A	27	10 M	26	11 A	25	0 A	24	12 A
68	1791	19	6 A	18	7 M	16	7 A	16	8 M	14	9 A	14	10 M
69	1792	8	3 M	6	4 A	5	4 A	4	5 A	3	6 M	2	7 A
70	1793	27	1 M	25	1 A	24	2 M	23	3 A	22	4 M	21	4 A
71	1794	16	9 M	14	10 A	13	10 M	12	11 A	11	0 A	11	1 M
72	1795	5	6 A	4	7 M	2	7 A	2 31	8 M 9 A	30	10 M	29	10 A
73	1796	23	3 A	22	4 M	20	4 A	20	5 M	18	6 A	18	7 M
74	1797	12	12 A	11	1 A	10	1 M	9	2 A	8	3 M	7	4 A
75	1798	2 31	9 M 10 A	30	10 M	28	11 A	28	0 A	27	1 M	26	1 A
76	1799	21	6 M	19	8 A	18	8 M	17	9 A	16	10 M	15	11 A
1	1800	9	3 A	8	4 M	6	4 A	6	5 M	4	6 A	4	7 M

388. The Cycle of Easter, also called the Dionysian Period, is a revolution of 532 years, found by multiplying the solar cycle 28 by the lunar cycle 19. If the new moons did not anticipate upon this cycle, Easter-day would always be the Sunday next after the first full moon which follows the 21st of March. But, on account of the above anticipation, § 422, to which no proper regard was paid before the late alteration of the style, the Ecclesiastic Easter has several times been a week different from the true Easter within this last century. This inconvenience is now remedied by making the table, which used to find Easter for ever, in the common prayer book, of no longer use than the lunar difference from the new style will admit of.

Easter cycle deficient.

389. The earliest Easter possible, is the 22d of March, the latest the 25th of April. Within these limits are 35 days, and the number belonging to each of them, is called the number of direction; because thereby the time of Easter is found for any given year. To find the number of direction, according to the new style, enter Table V, at the end of this chapter, with the complete hundreds of any given year at the top, and the years thereof (if any) below an hundred, at the left hand; and where the columns meet, is the dominical letter for the given year. Then enter Table I, with the complete hundreds of the same year at the left hand, and the years below an hundred, at the top; and where the columns meet, is the golden number for the same year. Lastly, enter Table II, with the dominical letter at the left hand, and golden number at the top; and where the columns meet, is the number of direction for that year; which number, added to the 21st day of March, shews on what day either of March or April Easter Sunday falls in that year. Thus the dominical letter, new style, for the year 1757, is *B* (Table V.) and the golden number is 10, (Table I), by which, in Table II, the number of direction is found to be 20; which, reckoning from the 21st of March, ends on the 10th of April, that is Easter Sunday, in the year 1757.*

Number of direction.

To find the true Easter.

N. B. There are always two dominical letters to the leap-year, the first of which takes place to the 24th of February, the last for the following part of the year.

* A new and infallible method of finding Easter, without any reference to the Lunar motions, discovered by M. Gauss, will be found in the Edinburgh Encyclopædia. Art. Chronology. vol. vi. p. 411. 412.—*Ed.*

390. The first seven letters of the alphabet are commonly placed in the annual almanacks, to shew on what days of the week the days of the months fall throughout the year. And because one of those seven letters must necessarily stand against Sunday, it is printed in a capital form, and called the dominical letter: the other six being inserted in small characters, to denote the other six days of the week. Now, since a common Julian year contains 365 days, if this number be divided by 7 (the number of days in a week), there will remain one day. If there had been no remainder, it is plain the year would constantly begin on the same day of the week. But since 1 remains, it is as plain that the year must begin and end on the same day of the week; and therefore the next year will begin on the day following. Hence, when January begins on Sunday, *A* is the dominical or Sunday letter for that year: then, because the next year begins on Monday, the Sunday will fall on the seventh day, to which is annexed the seventh letter *G*, which therefore will be the dominical letter for all that year: and as the third year will begin on Tuesday, the Sunday will fall on the sixth day; therefore *F* will be the Sunday letter for that year. Whence it is evident, that the Sunday letters will go annually in a retrograde order thus; *G*, *F*, *E*, *D*, *C*, *B*, *A*. And in the course of seven years, if they were all common ones, the same days of the week, and dominical letters, would return to the same days of the months. But because there are 366 days in a leap-year, if this number be divided by 7, there will remain two days over and above the 52 weeks of which the year consists. And therefore, if the leap-year begins on Sunday, it will end on Monday; and the next year will begin on Tuesday, the first Sunday whereof must fall on the sixth of January, to which is annexed the letter *F*, and not *G*, as in common years. By this means, the leap-year returning every fourth year, the order of the dominical letters is interrupted, and the series cannot return to its first state till after four times seven, or 28 years; and then the same days of the months return in order to the same days of the week as before. Dominical letter.

391. *To find the Dominical letter for any year, either before or after the Christian era.* In Table III, or IV, for old style, or V, for new style, look for the hundreds of years at the head of the table, and for the years below an hundred (to make up the given year), at the To find the dominical letter.

left hand; and where the columns meet, you have the dominical letter for the year desired. Thus, suppose the dominical letter be required for the year of Christ 1758, new style, I look for 1700 at the head of Table V, and for 58 at the left hand of the same table; and in the angle of meeting, I find *A*, which is the dominical letter for that year. If it was wanting for the same year old style, it would be found by Table IV, to be *D*. But to find the dominical letter for any given year before Christ, subtract one from that year, and then proceed in all respects as just now taught, to find it by Table III. Thus, suppose the dominical letter be required for the 585th year before the first year of Christ, look for 500 at the head of Table III, and for 84 at the left hand; in the meeting of these columns is *F E*, which were the dominical letters for that year, and shews that it was a leap-year, because leap-year has always two dominical letters.

To find the days of the months.

392. *To find the day of the month answering to any day of the week, or the day of the week answering to any day of the month, for any year past or to come.* Having found the dominical letter for the given year, enter Table VI, with the dominical letter at the head; and under it, all the days in that column are Sundays, in the divisions of the months; the next column to the right hand are Mondays; the next Tuesdays; and so on to the last column under *G*; from which go back to the column under *A*, and thence proceed towards the right hand as before. Thus, in the year 1757, the dominical letter, new style, is *B*, in Table V, then in Table VI, all the days under *B* are Sundays in that year, viz. the 2d, 9th, 16th, 23d, and 30th, of January and October; the 6th, 13th, 20th, and 27th of February, March, and November; the 3d, 10th, and 17th of April and July, together with the 31st of July; and so on to the foot of the column. Then, of course, all the days under *C* on Mondays, namely, the 3d, 10th, &c. of January and October; and so of all the rest in that column. If the day of the week answering to any day of the month be required, it is easily had from the same table by the letter that stands at the top of the column in which the given day of the month is found. Thus, the letter that stands over the 28th of May is *A*; and in the year 585 before Christ, the dominical letters were found to be *F E*, § 391; which being a leap-year, and *E* taking place from the 24th of February to the end of that year, shews by the table

that the 25th of May was on a Sunday; and therefore the 28th must have been on a Wednesday; for when *E* stands for Sunday, *F* must stand for Monday, *G* for Tuesday, &c. Hence, as it is said that the famous eclipse of the Sun foretold by Thales, by which a peace was brought about between the Medes and Lydians, happened on the 28th of May, in the 585th year before Christ, it fell on a Wednesday

Julian period.

393. From the multiplication of the solar cycle of 28 years, into the lunar cycle of 19 years, and the Roman indiction of 15 years, arises the great Julian period, consisting of 7980 years, which had its beginning 764 years before Strauchius's supposed year of the creation (for no later could all the three cycles begin together), and it is not yet completed: and therefore it includes all other cycles, periods, and eras. There is but one year in the whole period that has the same numbers for the three cycles of which it is made up: and therefore, if historians had remarked in their writings the cycles of each year, there had been no dispute about the time of any action recorded by them.

To find the year of this period.

394. The Dionysian, or vulgar era of Christ's birth, was about the end of the year of the Julian period 4713; and consequently the first year of his age, according to that account, was the 4714th year of the said period. Therefore, if to the current year of Christ we add 4713, the sum will be the year of the Julian period. So the year 1757 will be found to be the 6470th year of that period. Or, to find the year of the Julian period answering to any given year before the first year of Christ, subtract the number of that given year from 4714, and the remainder will be the year of the Julian period. Thus, the year 585 before the first year of Christ (which was the 584th before his birth), was the 4129th year of the said period. Lastly, to find the cycles of the Sun, Moon, and indiction, for any given year of this period, divide the given year by 28, 19, and 15; the three remainders will be the cycles sought, and the quotients the numbers of cycles run since the beginning of the period. So in the above 4714th year of the Julian period, the cycle of the Sun was 10, the cycle of the Moon 2, and the cycle of indiction 4; the solar cycle having run through 168 courses, the lunar 248, and the indiction 314.

And the cycles of that year.

The true era of Christ's birth.

395. The vulgar era of Christ's birth was never settled till the year 527, when Dionysius Exiguus, a Roman abbot, fixed it to the end of the 4713th year of the Julian period, which was four years too late. For our Saviour was born before the death of Herod, who sought to kill him as soon as he heard of his birth. And, according to the testimony of Josephus (B. xvii, ch. 8), there was an eclipse of the Moon in the time of Herod's last illness; which eclipse appears, by our astronomical tables, to have been in the year of the Julian period 4710, March 13th, at 3 hours past midnight, at Jerusalem. Now, as our Saviour must have been born some months before Herod's death, since in the interval he was carried into Egypt, the latest time in which we can fix the true era of his birth, is about the end of the 4709th year of the Julian period.

There is a remarkable prophecy delivered to us in the ninth chapter of the book of Daniel, which, from a certain epoch, fixes the time of restoring the state of the Jews, and of building the walls of Jerusalem, the coming of the Messiah, his death, and the destruction of Jerusalem. But some parts of this prophecy (ver. 25), are so injudiciously pointed in our English translation of the bible, that, if they be read according to those stops of pointing, they are quite unintelligible. But the learned Dr. Prideaux, by altering these stops, makes the sense very plain: and as he seems to me to have explained the whole of it better than any other author I have read on the subject, I shall set down the whole of the prophecy according as he has pointed it, to shew in what manner he has divided it into four different parts.

Ver. 24. ' Seventy weeks are determined upon thy people, ' and upon thy holy city, to finish the transgression, and to ' make an end of sins, and to make reconciliation for iniquity, ' and to bring in everlasting righteousness, and to seal up the ' vision, and the prophecy, and to anoint the most holy. *Ver.* ' 25. Know therefore and understand, that from the going ' forth of the commandment to restore and build Jerusalem ' unto the Messiah, the prince shall be seven weeks and three- ' score and two weeks, the street shall be built again, and the ' wall even in troublous times. *Ver.* 26. And after threescore ' and two weeks shall Messiah be cut off, but not for himself,

'and the people of the prince that shall come, shall destroy 'the city and sanctuary, and the end thereof shall be with a 'flood, and unto the end of the war desolations are determined. '*Ver.* 27. And he shall confirm the covenant with many for 'one week, and in the midst[1] of the week he shall cause the 'sacrifice and the oblation to cease, and for the overspreading 'of abominations he shall make it desolate even until the con- 'summation, and that determined shall be poured upon the 'desolate.'

This commandment was given to Ezra by Artaxerxes Longimanus, in the seventh year of that king's reign (Ezra, ch. vii, ver 11–26) Ezra began the work, which was afterwards accomplished by Nehemiah; in which they met with great opposition and trouble from the Samaritans and others, during the first seven weeks, or 49 years.

From this accomplishment, till the time when Christ's messenger, John the Baptist, began to preach the kingdom of the Messiah, 62 weeks, or 434 years.

From thence, to the beginning of Christ's public ministry, half a week, or 3½ years.

And from thence to the death of Christ, half a week, or 3½ years; in which half week he preached, and confirmed the covenant of the gospel with many

In all, from the going forth of the commandment till the death of Christ, 70 weeks, or 490 years.

And, lastly, in a very striking manner, the prophecy foretels what should come to pass after the expiration of the seventy weeks; namely, the destruction of the city and sanctuary by the people of the prince that was to come; which were the Roman armies, under the command of Titus their prince, who came upon Jerusalem as a torrent, with their idolatrous images, which were an abomination to the Jews, and under which they marched against them, invaded their land, and besieged their holy city, and by a calamitous war brought such utter destruction upon both, that the Jews have never been able to recover themselves, even to this day.

Now, both by the undoubted canon of Ptolemy, and the famous era of Nabonassar, the beginning of the seventh year of

[1] The Doctor says, that this ought to be rendered, the half part of the week, not the midst.

the reign of Artaxerxes Longimanus, king of Persia (who is called Ahasuerus in the book of Esther), is pinned down to the 4256th year of the Julian period, in which year he gave Ezra the above-mentioned ample commission: from which count 490 years to the death of Christ, and it will carry the same to the 4746th year of the Julian period.

Our Saturday is the Jewish Sabbath: and it is plain, from St. Mark, ch. xv, ver. 42, and St. Luke, ch. xxiii, ver. 54, that Christ was crucified on a Friday, seeing the crucifixion was on the day next before the Jewish Sabbath. And, according to St. John, ch. xviii, ver. 28, on the day that the passover was to be eaten, at least by many of the Jews.

The Jews reckoned their months by the Moon, and their years by the apparent revolution of the Sun: and they eat the passover on the 14th day of the month of Nisan, which was the first month of their year, reckoning from the first appearance of the new moon, which at that time of the year might be on the evening of the day next after the change, if the sky was clear. So that their 14th day of the month answers to our 15th day of the Moon, on which she is full. Consequently, the passover was always kept on the day of full Moon.

And the full Moon at which it was kept, was that one which happened next after the vernal equinox. For Josephus expressly says (Antiq. B. iii, ch. 10), 'The passover was kept 'on the 14th day of the month of Nisan, according to the 'Moon, when the Sun was in Aries.' And the Sun always enters Aries at the instant of the vernal equinox; which, in our Saviour's time, fell on the 22d day of March.

The dispute among chronologers about the year of Christ's death, is limited to four or five years at most. But, as we have shewn that he was crucified on the day of a pascal full moon, and on a Friday, all that we have to do, in order to ascertain the year of his death, is only to compute in which of those years there was a passover full Moon on a Friday. For, the full Moons anticipate eleven days every year (12 lunar months being so much short of a solar year), and therefore, once in every three years at least, the Jews were obliged to set their passover a whole month forwarder than it fell by the course of the Moon, on the year next before, in order to keep it at the full Moon next after the equinox; therefore, there could not be two passovers on the same nominal day of the week, within the

compass of a few neighbouring years. And I find by calculation, the only passover full Moon that fell on a Friday, for several years before or after the disputed year of the crucifixion, was on the 3d day of April, in the 4746th year of the Julian period, which was the 490th year after Ezra received the above-mentioned commission from Artaxerxes Longimanus, according to Ptolemy's canon, and the year in which the Messiah was to be cut off, according to the prophecy, reckoning from the going forth of that commission or commandment: and this 490th year was the 33d year of our Saviour's age, reckoning from the vulgar era of his birth; but the 37th, reckoning from the true era thereof.

And, when we reflect on what the Jews told him, some time before his death (John viii, 57), "Thou art not yet fifty "years old," we must confess, that it should seem much likelier to have been said to a person near forty, than to one but just turned of thirty. And we may easily suppose, that St. Luke expressed himself only in round numbers, when he said that Christ was baptized about the 30th year of his age, when he began his public ministry; as our Saviour himself did, when he said he should lie three days and three nights in the grave.

The 4746th year of the Julian period, which we have astronomically proved to be the year of the crucifixion, was the 4th year of the 202d Olympiad; in which year, Phlegon, a heathen writer, tells us, there was the most extraordinary eclipse of the Sun that ever was seen. But I find by calculation, that there could be no total eclipse of the Sun at Jerusalem, in a natural way in that year. So that what Phlegon here calls an eclipse of the Sun, seems to have been the great darkness for three hours at the time of our Saviour's crucifixion, as mentioned by the evangelists: a darkness altogether supernatural, as the Moon was then in the side of the heavens opposite to the Sun; and therefore could not possibly darken the Sun to any part of the Earth.

396. As there are certain fixed points in the heavens from which astronomers begin their computations, so there are certain points of time from which historians begin to reckon; and these points, or roots of time, are called eras or epochs. The most remarkable eras are those of the creation, the Greek Olympiads, the building of Rome, the era of Nabonassar, the death of

Alexander, the birth of Christ, the Arabian Hegira, and the Persian Yesdegird: all which, together with several others of less note, have their beginnings in the following table fixed to the years of the Julian period, to the age of the world at those times, and to the years before and after the year of Christ's birth.

*A Table of remarkable Eras and Events.**

		Julian period.	Y. of the world.	Before Christ.
	The creation of the world	706	0	4007
	The deluge, or Noah's flood	2362	1656	2351
3.	The Assyrian monarchy founded by Nimrod	2537	1831	2176
4.	The birth of Abraham	2714	2008	1999
5.	The destruction of Sodom and Gomorrah	2816	2110	1897
6.	The beginning of the kingdom of Athens by Cecrops	3157	2451	1556
7.	Moses receives the ten commandments	3222	2516	1491
8.	The entrance of the Israelites into Canaan	3262	2556	1451
9.	The Argonautic expedition	3450	2744	1263
10.	The destruction of Troy	3529	2823	1184
11.	The beginning of King David's reign	3650	2944	1063
12.	The foundation of Solomon's temple	3701	2995	1012
13.	Lycurgus forms his excellent laws	3829	3103	884
14.	Arbaces, the first king of the Medes	3838	3132	875
15.	Mandaucus, the second	3865	3159	848
16.	Sosarmus, the third	3915	3209	798
17.	The beginning of the Olympiads	3938	3232	775
18.	Artica, the fourth king of the Medes	3945	3239	768
19.	The Catonian epocha of the building of Rome	3961	3255	752
20.	The era of Nabonassar	3967	3261	746
21.	The destruction of Samaria by Salmaneser	3992	3286	721
22.	The first eclipse of the moon on record	3993	3287	720
23.	Cardicea, the fifth king of the Medes	3996	3290	717
24.	Phraortes, the sixth	4058	3352	655
25.	Cyaxares, the seventh	4080	3374	633
26.	The first Babylonish captivity by Nebuchadnezzar	4107	3401	606
27.	The long war ended between the Medes and Lydians	4111	3405	602
28.	The second Babylonish captivity, and birth of Cyrus	4114	3408	599
29.	The destruction of Solomon's temple	4125	3419	588
30.	Nebuchadnezzar struck with madness	4144	3438	569
31.	Daniel's vision of the four monarchies	4158	3452	555
32.	Cyrus begins to reign in the Persian empire	4177	3471	536
33.	The battle of Marathon	4223	3517	490
34.	Artaxerxes Longimanus begins to reign	4249	3543	464
35.	The beginning of Daniel's 70 weeks of years	4256	3550	457
36.	The beginning of the Peloponnesian war	4282	3576	431
37.	Alexander's victory at Arbela	4383	3677	330
38.	His death	4390	3684	323
39.	The captivity of 100,000 Jews by King Ptolemy	4393	3687	320
40.	The Colossus of Rhodes thrown down by an earthquake	4491	3875	222
41.	Antiochus defeated by Ptolemy Philopater	4496	3790	217
42.	The famous Archimedes murdered at Syracuse	4506	3800	207
43.	Jason butchers the inhabitants of Jerusalem	4543	3837	170
44.	Corinth plundered and burnt by Consul Mummius	4567	3861	146

* A very copious Chronological Table, down to 1813, and containing many topics not before introduced into tables of that kind, will be found in the EDINBURGH ENCYCLOPÆDIA, Art. CHRONOLOGY, vol. vi, p. 417-461.—*Ed.*

	Julian period	Y. of the world.	Before Christ
45. Julius Cæsar invades Britain...	4659	395	54
46. He corrects the calendar..............................	4677	396	46
47. Is killed in the senate-house.....	4671	3965	42
48. Herod made king of Judea..............................	4673	3967	40
49. Anthony defeated at the battle of Actium	4683	3977	30
50. Agrippa builds the Pantheon at Rome	4688	3982	25
51. The true era of Christ's birth.	4709	4003	4
52. The death of Herod.	4710	4004	3
			After Christ
53. The Dionysian, or vulgar era of Christ's birth............	4713	4007	0
54. The true year of his crucifixion.....	4746	4040	33
55. The destruction of Jerusalem..	4783	4077	70
56. Adrian builds the long wall in Britain........................	4833	4127	120
57. Constantius defeats the Picts in Britain.......................	5019	4313	306
58. The council of Nice	5038	4332	325
59. The death of Constantine the Great	5050	4344	337
60. The Saxons invited into Britain..................................	5158	4452	445
61. The Arabian Hegira..	5335	4629	622
62. The death of Mahommed, the pretended prophet.........	5343	4637	630
63. The Persian Yesdegird..	5344	4638	631
64. The Sun, Moon, and all the planets in Libra, Sept. 14, as seen from the Earth..	5899	5193	1186
The art of printing discovered...........	6153	5447	1440
66. The reformation begun by Martin Luther.............	6230	5524	1517

Age of the world uncertain.

In fixing the year of the creation to the 706th year of the Julian period, which was the 4007th year before the year of Christ's birth, I have followed Mr. Bedford in his Scripture Chronology, printed A. D. 1730, and Mr. Kennedy, in a work of the same kind, printed A. D. 1762.—Mr. Bedford takes it only for granted that the world was created at the time of the autumnal equinox; but Mr. Kennedy affirms, that the said equinox was at the noon of the fourth day of the creation-week, and that the Moon was then 24 hours past her opposition to the Sun.—If Moses had told us the same things, we should have had sufficient data for fixing the era of the creation; but, as he has been silent on these points, we must consider the best accounts of chronologers as entirely hypothetical and uncertain.

Table I. Shewing the Golden Number (which is the same both in the Old and New Style) from the Christian Era to A. D. 3800.

Hundreds of Years.		Years less than an hundred.																		
		0 19 38 57 76 95	1 20 39 58 77 96	2 21 40 59 78 97	3 22 41 60 79 98	4 23 42 61 80 99	5 24 43 62 81	6 25 44 63 82	7 26 45 64 83	8 27 46 65 84	9 28 47 66 85	10 29 48 67 86	11 30 49 68 87	12 31 50 69 88	13 32 51 70 89	14 33 52 71 90	15 34 53 72 91	16 35 54 73 92	17 36 55 74 93	18 37 56 75 94
0	1900	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
100	2000	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5
200	2100	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10
300	2200	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
400	2300	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1
500	2400	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6
600	2500	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11
700	2600	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
800	2700	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2
900	2800	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7
1000	2900	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12
1100	3000	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1200	3100	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3
1300	3200	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8
1400	3300	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13
1500	3400	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1600	3500	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4
1700	3600	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9
1800	3700	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Table II. Shewing the Number of Direction for finding Easter Sunday by the Golden Number and Dominical Letter.

G. N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A	26	19	5	26	12	33	19	12	26	19	5	26	12	5	26	12	33	19	12
B	27	13	6	27	13	34	20	13	27	20	6	27	13	6	20	13	34	20	6
C	28	14	7	21	14	35	21	7	28	21	7	28	14	7	21	14	28	21	7
D	29	15	8	22	15	29	22	8	29	15	8	29	15	1	22	15	29	22	8
E	30	16	2	23	16	30	23	9	30	16	9	23	16	2	23	9	30	23	9
F	24	17	3	24	10	31	24	10	31	17	10	24	17	3	24	10	31	17	10
G	25	18	4	25	11	32	18	11	32	18	4	25	18	4	25	11	32	18	11

This Table is adapted to the New Style.

Table III. Shewing the Dominical Letter, Old Style, for 4200 *Years before the Christian Era.*

Bef. Christ.				Hundreds of Years.						
Years less than an Hundred.				0 700 1400 2100 2800 3500	100 800 1500 2200 2900 3600	200 900 1600 2300 3000 3700	300 1000 1700 2400 3100 3800	400 1100 1800 2500 3200 3900	500 1200 1900 2600 3300 4000	600 1300 2000 2700 3400 4100
0	28	56	84	D C	C B	B A	A G	G F	F E	E D
1	29	57	85	E	D	C	B	A	G	F
2	30	58	86	F	E	D	C	B	A	G
3	31	59	87	G	F	E	D	C	B	A
4	32	60	88	B A	A G	G F	F E	E D	D C	C B
5	33	61	89	C	B	A	G	F	E	D
6	34	62	90	D	C	B	A	G	F	E
7	35	63	91	E	D	C	B	A	G	F
8	36	64	92	G F	F E	E D	D C	C B	B A	A G
9	37	65	93	A	G	F	E	D	C	B
10	38	66	94	B	A	G	F	E	D	C
11	39	67	95	C	B	A	G	F	E	D
12	40	68	96	E D	D C	C B	B A	A G	G F	F E
13	41	69	97	F	E	D	C	B	A	G
14	42	70	98	G	F	F	D	C	D	A
15	43	71	99	A	G	F	E	D	C	B
16	44	72		C B	B A	A G	G F	F E	E D	D C
17	45	73		D	C	B	A	G	F	E
18	46	74		E	D	C	B	A	G	F
19	47	75		F	E	D	C	B	A	G
20	48	76		A G	G F	F E	E D	D C	C B	B A
21	49	77		B	A	G	F	E	D	C
22	50	78		C	B	A	G	F	E	D
23	51	79		D	—	B	A	G	F	E
24	52	80		F E	E D	D C	C B	B A	A G	G F
25	53	81		G	F	E	D	C	B	A
26	54	82		A	G	F	E	D	C	B
27	55	83		B	A	G	F	E	D	C

Table IV. Shewing the Dominical Letter, Old Style, for 4200 Years after the Christian Era.

After Christ.				Hundreds of Years.						
Years less than an Hundred.				0 700 1400 2100 2800 3500	100 800 1500 2200 2900 3600	200 900 1600 2300 3000 3700	300 1000 1700 2400 3100 3800	400 1100 1800 2500 3200 3900	500 1200 1900 2600 3300 4000	600 1300 2000 2700 3400 4100
0	28	56	84	D C	E D	F E	G F	A G	B A	C B
1	29	57	85	B	C	D	E	F	G	A
2	30	58	86	A	B	C	D	E	F	G
3	31	59	87	G	A	B	C	D	E	F
4	32	60	88	F E	G F	A G	B A	C B	D C	E D
5	33	61	89	D	E	F	G	A	B	C
6	34	62	90	C	D	E	F	G	A	B
7	35	63	91	B	C	D	E	F	G	A
8	36	64	92	A G	B A	C B	D C	E D	F E	G F
9	37	65	93	F	G	A	B	C	D	E
10	38	66	94	E	F	G	A	B	C	D
11	39	67	95	D	E	F	G	A	B	C
12	40	68	96	C B	D C	E D	F E	G F	A G	B A
13	41	69	97	A	B	C	D	E	F	G
14	42	70	98	G	A	B	C	D	E	F
15	43	71	99	F	G	A	B	C	D	E
16	44	72		E D	F E	G F	A G	B A	C B	D C
17	45	73		C	D	E	F	G	A	B
18	46	74		B	C	D	E	F	G	A
19	47	75		A	B	C	D	E	F	G
20	48	76		G F	A G	B A	C B	D C	E D	F E
21	49	77		E	F	G	A	B	C	D
22	50	78		D	E	F	G	A	B	C
23	51	79		C	D	E	F	G	A	B
24	52	80		B A	C B	D C	E D	F E	G F	A G
25	53	81		G	A	B	C	D	E	F
26	54	82		F	G	A	B	C	D	E
27	55	83		E	F	G	A	B	C	D

Table V. The Dominical Letter, New Style, for 4000 Years after the Christian Era.

After Christ.				Hundreds of Years.			
Years less than an Hundred.				100 500 900 1300 1700 2100 2500 2900 3300 3700	200 600 1000 1400 1800 2200 2600 3000 3400 3800	300 700 1100 1500 1900 2300 2700 3100 3500 3900	400 800 1200 1600 2000 2400 2800 3200 3600 4000
				C	E	G	B A
1	29	57	85	B	D	F	G
2	30	58	86	A	C	E	F
3	31	59	87	G	B	D	E
4	32	60	88	F E	A G	C B	D C
5	33	61	89	D	F	A	B
6	34	62	90	C	E	G	A
7	35	63	91	B	D	F	G
8	36	64	92	A G	C B	E D	F F
9	37	65	93	F	A	C	D
10	38	66	94	E	G	B	C
11	39	67	95	D	F	A	B
12	40	68	96	C B	E D	G F	A G
13	41	69	97	A	C	E	F
14	42	70	98	G	B	D	E
15	43	71	99	F	A	C	D
16	44	72		E D	G F	B A	C B
17	45	73		C	E	G	A
18	46	74		B	D	F	G
19	47	75		A	C	E	F
20	48	76		G F	B A	D C	E D
21	49	77		E	G	B	C
22	50	78		D	F	A	B
23	51	79		C	E	G	A
24	52	80		B A	D C	F E	G F
25	53	81		G	B	D	E
26	54	82		F	A	C	D
27	55	83		E	G	B	C
28	56	84		D C	F E	A G	B A

Table VI. Shewing the Days of the Months for both Styles, by the Dominical Letter.

Week Days.	A	B	C	D	E	F	G
January, 31, October, 31,	1 8 15 22 29	2 9 16 23 30	3 10 17 24 31	4 11 18 25	5 12 19 26	6 13 20 27	7 14 21 28
February, 28–29, March, 31, November, 30,	5 12 19 26	6 13 20 27	7 14 21 28	1 8 15 22 29	2 9 16 23 30	3 10 17 24 31	4 11 18 25
April, 30, July, 30,	2 9 16 23 30	3 10 17 24 31	4 11 18 25	5 12 19 26	6 13 20 27	7 14 21 28	1 8 15 22 29
August, 31,	6 13 20 27	7 14 21 28	1 8 15 22 29	2 9 16 23 30	3 10 17 24 31	4 11 18 25	5 12 19 26
September, 30, December, 31,	3 10 17 24 31	4 11 18 25	5 12 19 26	6 13 20 27	7 14 21 28	1 8 15 22 29	2 9 16 23 30
May, 31,	7 14 21 28	1 8 15 22 29	2 9 16 23 30	3 10 17 24 31	4 11 18 25	5 12 19 26	6 13 20 27
June, 30,	4 11 18 25	5 12 19 26	6 13 20 27	7 14 21 28	1 8 15 22 29	2 9 16 23 30	3 10 17 24

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END OF THE FIRST VOLUME.

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